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FEASIBILITY STUDY FOR AN AUTOMATED DIGITIZED DOCUMENT STORAGE, --ETC(U)
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REPORT NO. MT-028
FEBRUARY 1976

FEASIBILITY STUDY FOR AN AUTOMATED, DIGITIZED DOCUMENT STORAGE, RETRIEVAL AND TRANSMISSION SYSTEM

(ADDSRTS)

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A PROJECT OF THE
MANUFACTURING TECHNOLOGY PROGRAM
NAVAL SEA SYSTEMS COMMAND

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FINAL REPORT

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NAVAL ORDNANCE STATION
LOUISVILLE, KENTUCKY 40214

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FEASIBILITY STUDY FOR AN AUTOMATED, DIGITIZED DOCUMENT STORAGE, RETRIEVAL AND TRANSMISSION SYSTEM (ADDSRTS)

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ABSTRACT

This study assesses the technology and availability of equipment for providing an automated storage, retrieval and transmission system for engineering drawings by converting them into a digitized data stream. Examination of current technology and available equipment revealed that little progress has been made in the mass storage of data. Only a few companies and the Department of the Army have made studies in image conversion to data stream and resolution relationships. One company has done extensive research in the use of laser scanning in the conversion to data stream of microfilm images of engineering drawings. This data stream requires approximately 80 x 10^6 bits to describe adequately an E size drawing at a suitable level of resolution. Because of the large amount of data involved, the company also examined data compaction and compression techniques for this data stream. They found that an average of 40:1 reduction was realistic, thus reducing the data per image to 2 x 10^6 bits. A mass storage concept was then formulated that is based on an analysis of this information plus a consideration of the make-up and activity at the Naval Ordnance Station, Louisville (NOSL). Review of the present and newly emerging data stream storage media indicated that no substantial breakthrough could be anticipated, especially with regard to cost per bit or the overall on-line capacity. Because the storage information must be archival, only one system was found to offer suitable storage media. Its cost per bit is competitive, and it can provide through modular units an on-line storage for 10 x 10^{12} bits or enough capacity for 5-million engineering drawings. Additional investigation has revealed that the bits per image can be further reduced to 1.5 x 10^6 and that the technology is available to provide a mass store with access of two megabits a second and a capacity of 2 x 10^{12} bits within a 2 1/2 foot cube. This study, therefore, concludes:

The following conclusions are drawn from this study:

(1) An Advanced Mass Store is important to the entire electronic data store industry and should be strongly supported;

(2) An automated storage, retrieval and transmission system is practicable,

(3) The technology is available for such a system; and

(4) Two major items of equipment, however, are not commercially available at this time:—

(a) An inputting device to read engineering drawings or microfilm of engineering drawings, and

(b.) An outputting device to reconstruct the image on film for contract data packages.

The study ~~which follows~~ reviews technologies, equipment, requirements for implementation, and an economic analysis of a system for NOSL.

→ the Naval Ordnance Station, Louisville.

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JUSTIFICATION
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FOREWORD

This is the final report of work completed under NAVORDSYSCOM Work Request WR-4-5975 issued to perform a feasibility study of an automated system for the storage, retrieval and transmission of engineering drawings by conversion of the document into a digitized data stream. The study was performed by the Naval Ordnance Station, Louisville, Kentucky.

Funding was provided by the Industrial Resources and Facilities Division (ORD-047) of Naval Ordnance Systems Command and completed for Naval Sea Systems Command (SEA-070) as part of the Manufacturing Technology Program.

Acknowledgement is given to the following persons who provided valuable knowledge and expertise, and without whose help this comprehensive study would be incomplete:

Frank Lewandowski	Singer Simulation Products, California
Dr. Nicholas S. Szabo	Singer Simulation Products, California
H. Gene Eldridge	Precision Instrument Co. (Washington office)

This Manufacturing Technology report has been reviewed and is approved.

D. McMahon

DERRICK McMAHON
Director, Manufacturing
Technology Department
Naval Ordnance Station
Louisville, Kentucky

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SECTION 1

INTRODUCTION

1.1 OBJECTIVE

This study was performed to determine the feasibility, in terms of technology and currently available hardware, of implementing an automated system for the storage, retrieval and transmission of engineering drawings by conversion of the document into an electronic data stream. The data stream must be capable of being processed and controlled by means of a computer. The overall system to be considered must be a replacement for the present manually operated microfilm aperture card file and master drawing repository at the Naval Ordnance Station, Louisville (NOSL).

1.2 BACKGROUND

With the ever increasing accumulation of engineering drawings, there are many agencies within the U. S. Government, and within the Department of Defense in particular, which must manage huge document handling systems. With drawings numbering in the millions, even the use of microfilm, microfiche or aperture cards does not alleviate the problems of storage and retrieval when such large quantities are involved. Thus, the need to provide a totally automated system of handling and storing is of paramount importance.

The continuing review of methods and procedures in the constant search for greater productivity and efficiency, coupled with an article on storage and retrieval[1], triggered a review of the present procedures at NOSL. The Technical Documents Department of NOSL is the respository for approximately 4 1/2 million engineering drawings pertaining to Naval Ordnance Systems and components, together with other associated documents (e.g., data lists, weapons specifications, etc.), and technical publications. The service provided related to engineering drawing requests falls into two main categories: one, single and multiple drawing requests; two, requests for contract data packages.

a. Single and Multiple Drawing Requests. In-house requests are generated typically for the following reasons:

(1) New Manufacture of Overhaul/Rehabilitation, which includes:

Preparation of master production schedules;
Examination for make, buy or repair decisions;
Preparation of method sheets for new manufacture or rework;
Production control packages;
Quality assurance - inspection, test procedures, etc.

(2) Engineering Support, which includes:

Producibility reviews;
Production engineering support;
In-service engineering technical support;
Drawing revisions and updating;
Field engineering support;
New design.

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(3) Requests from other sources, which include:

Other Navy field activities;
Major contractors.

b. Contract Data Packages. This item constitutes the major effort of the department and is required for support of:

(1) Station initiated procurements through the Contracting Department.

(2) Preparation of bid packages for other Navy activities (i.e., Ships Parts Control Center - SPCC Mechanicsburg) and for Naval Material Command (NAVMAT).

1.3 CONCEPTUAL REQUIREMENTS †

It was decided that the system should be capable of producing a data stream to represent engineering drawings of various sizes; performing compression techniques on the data to reduce them to their most compact form; storing the resulting information in an on-line and/or off-line storage system so as to provide for remote retrieval of the drawings.

The input device/s should be capable of inputting drawings at the rate of 25 per hour. The system must be able to handle at least 3 million drawings in its on-line storage, and, if necessary, 2 million drawings off-line.

With the digitized drawings stored in a compacted form, the system should then provide for retrieving the drawings in two ways. The first retrieval requirement is that operators at remote terminals (up to a 1/4 mile from the mass memory and control center) be able to retrieve specific drawings for viewing on suitable display devices. The terminal must be capable of allowing the operator to view the entire drawing (it is recognized that this will mean at significantly reduced resolution), and also to select an area of the total drawing for display at increased resolution sufficient to allow for reading detailed information on the drawing (zoom capability).

The system should be able to handle an average total of approximately 900 random requests per day (115/hour) from 15 such terminals, while retaining an average response time under 10 seconds from on-line storage and 5 minutes from off-line storage. The second retrieval requirement is for large groups of related documents to be retrievable from storage and outputted on 35mm microfilm or similar material at a rate of approximately 285 documents per hour. This output microfilm shall have resolution quality as good as, or better than, that specified in MIL-M-9868. For a Class I drawing at 16X reduction, MIL-M-9868 requires that microfilms shall provide resolution equivalent to 7.1 line pairs per mm on the original document distinguishable at any orientation.

A conceptual flow diagram is shown in Figure 1. The two types of input; vector data generated at the Graphics Art Center, and raster data generated from the microfilm are forwarded through data compression to mass storage. Output from mass storage is decompressed and forwarded for microfilm reimaging, or visual display.

†These requirements were formulated from analysis of the present system capability.

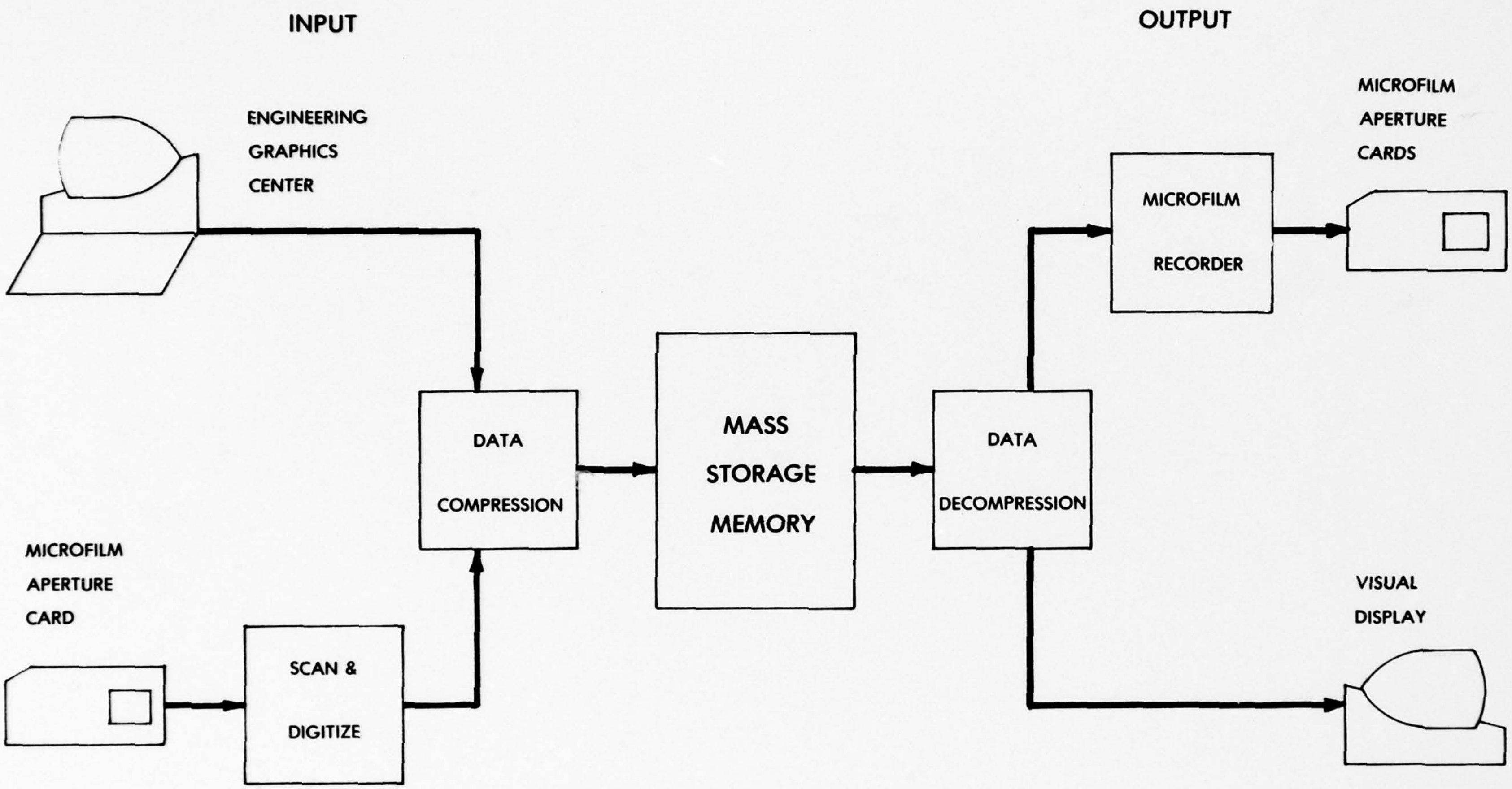

FIGURE 1

ADDSRTS CONCEPT SCHEMATIC

SECTION 2

INDUSTRY BACKGROUND

2.1 ANALYSIS OF THE PAST

It is only within the past 5 years or so that any technology has emerged which is suitable for the sophisticated requirements implied by ADDSRTS. Rather than analyze the history of the ADDSRTS industry, of which there is very little, this section traces the changing conditions that have led to the ADDSRTS concept.

With an ever increasing number of engineering drawings requiring handling, it became evident that, due to both large storage size and high retrieval time, the manual methods of handling engineering drawings were inadequate. Thus, when microfilm, microfiche and aperture card technology became available, most engineering drawing storage systems were converted to this type of storage. Although the advent of microfilm helped to relieve some of the problems associated with huge storage requirements, it did not provide an efficient solution to the problem of indexing drawings. Neither did it provide for conventiently low retrieval times or adequate security. (Microfilm was often lost or misfiled.)

It was with these problems in mind that much effort went into devising methods of automatically determining the address (the physical location) of the film or aperture cards and using the addresses to retrieve from the file with an automatically controlled device. Some systems of this kind were successfully designed, but the problem of access time remained, especially for large systems with huge numbers of aperture cards, since retrieval still required mechanical motion across a large area. These very large systems introduced another factor, that of reliability. While designs have paid great attention to this aspect, installed systems have shown that breakdowns and maintenance have proven to be a major and costly factor in very large systems. This is due to the nature of the medium and the complex and intricate electro-mechanical devices required.

These systems typically employ electro-mechanical retrieval equipment under the control of a mini-computer which contains the address of each engineering drawing apertue card. An operator may enter an engineering drawing number through a console of the computer control, which determines the address of that card, directs a mechanical device to retrieve it, and displays it on a visual display. The visual display is usually the normal optical microfilm viewer, though in the more sophisticated systems, closed circuit TV has been used to provide remote viewing. This system resolves most of the problems associated with file security and improves response time (typically 15 seconds[2] for large multiple access systems) over that of manual retrieval. Rapid access and/or plurality of requests increases the number of retrieval devices and viewing stations and consequently decreases reliability. Such is the state-of-the-art of engineering drawing storage and retrieval today.

2.2 CRITIQUE OF THE PRESENT

The sophisticated hardware and technology suggested by the ADDSRTS concept are either available in most cases, or, if not actually available, approximate the requirements. However, no known attempt has been made to date to con-

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nect all the necessary components to achieve ADDSRTS. For example, scanning and digitizing equipment has been built by various companies for R&D effort, but no known suitable commercial hardware exists. At least one company is known to have conducted extensive exploration into scanning, digitizing, data stream compression, and output resolution, specifically on engineering drawings. Equipment exists for scanning and digitizing documents (approximately 8 1/2 x 11 inch pages of text and/or graphics), but these are usually isolated systems and are not interfaced with large mass memory.

The largest known on-line mass memory system is believed to be that at NASA, Ames, Moffet Field, California, with one trillion bit capacity (1×10^{12} bits). The mass memory required for ADDSRTS is approximately 10×10^{12} bits, an order magnitude of 10. Predictions of mass storage media requirements made in 1973 by NSA [3], Fort Meade, Maryland, indicate that 10×10^{12} bits would not be uncommon in 1975, and that by 1980, 10×10^{15} and larger would be required.

The technology and modular units exist today which can be assembled to produce an on-line mass memory system of the capacity required for ADDSRTS. Although the technology for the ADDSRTS system exists, the actual analysis and design of a viable ADDSRTS is yet to be accomplished.

Listed below are some systems in operation today which use some of the parts of the ADDSRTS concept:

a. At the National Bureau of Standards [4], a system is operational which scans building diagrams and performs design analysis for fire prevention studies. The system employs a Film Optical Scanning Device for Input to a Computer (FOSDIC), which has been constructed from standard optical and electrical components and is run under minicomputer control to store data on standard magnetic tape. The overall system is efficient for its purpose, though it operates at fairly low speed and does not handle large volumes of data.

b. At the Department of Defense [5], a system called TABLON, with an on-line date capacity of over a trillion (1×10^{12}) bits, has been operational since 1969. This system employs a series of dedicated minicomputers working in coordination with an AMPEX Terabit Memory and an IBM 1360 Photodigital Cell Storage (which is no longer in production). The system provides rapid accessibility and distribution of data from its on-line files. In this system, however, no scanning or compaction of drawings is performed, and graphic data is not converted to digital data.

c. At General Motors Corporation [6] in Detroit, Michigan, a system is in use which provides terminal operators the capability of retrieving automotive design specifications for analysis from a central data base. In this system, however, no actual drawings are stored, but algorithms and groups of algorithms are stored which may be retrieved and used at remote terminals.

d. At the Department of the Army, Tank Automotive Command [7] (TACOM) in Detroit is located the largest known automated engineering drawing storage, retrieval and limited transmission system. The system under computer

control employs a MOSLER automatic aperture card storage and retrieval system (which is no longer in production). The aperture cards are made available at an output station for duplication for assembly into contract data packages or for visual display by microfilm viewer, or for remote viewing by closed circuit TV. This large system believed to have cost upwards of 4 1/2 million dollars, was amortized in less than one year by greatly reducing the lead time to assemble contract data packages for bids, which in turn permitted reduced inventory of spare parts. It is known that the Army has need for duplicate or similar systems within its other commands, but industry is reluctant to be involved, it is believed, primarily because of the maintenance and system support required.

These systems indicate a dire need for the mas storage of engineering drawings and similar documents and indicate that additional effort is needed in scanning and digitizing pictorial data, mass memory systems, and the bringing of the two technologies together to provide a viable ADDSRTS.

2.3 FUTURE PROSPECTS

The technology of scanning, digitizing, and data stream compression is known and can be exploited commercially when sufficient demand is demonstrated. This demand appears to have halted for the lack of large mass memory storage and the unavailability of a total system.

In the on-line mass memory field, which has been shown to be the core of the whole system, the inherent requirement is the durability and reliability of the storage media to withstand repeated use without degradation. For the ADDSRTS system, the storage media must be archival. (Engineering drawings within DOD cannot be destroyed without Congressional approval.)

SECTION 3

TECHNOLOGIES AND EQUIPMENT NEEDED FOR ADDSRTS

3.1 INPUT DEVICES

Two types of input devices are required: one, a device to provide a direct input from Graphic Arts Sub-Systems (Computer Aided Design, CAD), for new drawings and documents; two microfilm scanning devices to input existing drawings.

3.1.1 Graphic Arts Sub-System

These sub-systems are intended to be used primarily for the generation of new drawings and associated documents. However, with sound system design and software programming, they can be utilized as full interactive computer graphics systems.

A typical system consists of a large-screen storage tube display, an electronic pen (a light pencil), keyboard, plotter, central processor, and in some instances a programmable functional keyboard.

As drawings are developed, the system can also build a three-dimensional geometric data base - a precise, computerized graphic definition that is the common data base for design, documentation, bills of materials, production of NC control tapes, derivation of tool paths, and design and tooling of fixtures. Data can also be formatted for finite element analysis or other type design analysis and simulation.

The data stream from the system is usually a vectorized representation of the graphics in one of the common languages. Some systems have the capability of providing both input and output, as well as fine resolution plotting and character printing.

3.1.2 Microfilm Scanning Systems

The basic purpose of the scanner is to translate the microfilmed drawing into digital form. This is generally done by subdividing the image into small picture cells or pixels, measuring the optical density of each pixel, translating this optical density into digital form, and transferring the resulting digital data to an appropriate recording device.

3.1.2.1 Scan Patterns

The most straightforward and commonly used scanning pattern is the rectangular raster, which entails relatively simple driving logic for the scanner, and produces a relatively manageable x-y matrix of data elements for subsequent processing. More elaborate scanning modes have been used for some specialized applications. These modes include edge detection, vector recognition, symbol recognition and alphanumeric character recognition. Because of the amount of

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software involved, the feasibility of incorporating these special scanning modes into the ADDSRTS scanner is open to question.

3.1.2.2 Scanning Hardware and Techniques

a. Flying Spot Scanner

A conceptual diagram of the flying spot scanner is shown in Figure 2. As the figure indicates, a cathode and an accelerating grid, under control of a spot intensity device, produce an electron beam. This beam is channeled through a deflection coil which provides the magnetic field that directs the electron beam to the proper x-y coordinate on the face of the CRT. The magnetic field which determines the position of the electron beam is controlled by a raster driver which produces the electric currents necessary for each x-y coordinate, as specified by the system logic and control device. Once the spot is positioned properly on the CRT face, it is focused through the appropriate lenses to pass the light beam through the microfilm and into a photomultiplier which determines the intensity of the transmitted beam. The photomultiplier then emits an electric analog signal that describes the intensity of the light passing through the x-y coordinate. This signal is converted to digital form by an analog-to-digital converter, which then passes the digital information to the device which records the data.

This method of scanning and digitizing microfilm drawings is effective because it can be done at high speed under complete electronic control. However, the environment must be carefully controlled so that no extraneous magnetic field can destroy proper control of the electron beam.

b. Image Dissector

The method of scanning with an image dissector is illustrated in Figure 3. This method uses standard optics to focus an image of the aperture card drawing on the photocathode. The photocathode then produces an electro-optical image which is focused on the plane containing the aperture. The electrons produced by the photocathode enter the electron multiplier through the aperture. The output signals from the multiplier are collected and passed through an analog-to-digital converter, then to the digital recorder which stores the digital data. Generally, the resolution obtainable depends on the size of the dissecting aperture which may be as small as 10^{-3} inches.

c. Laser Scanner

The method of digitizing an engineering drawing aperture card by scanning it with a laser beam is illustrated in Figure 4. As the figure indicates, a laser beam is produced and directed first through an electro-optical modulator, then through a focusing lens which allows the beam to impinge upon a rotating mirror assembly. This assembly reflects the beam through the apeture card, held in place in a moveable platen. Stepping the beam across the microfilm in the x direction is achieved by the rotating mirror. Stepping the beam in the y direction occurs by moving the platen, which holds the aperture card, in precise synchronization with the movement of the rotating mirror. The laser beam passing through the microfilm strikes a photomultiplier where the intensity of the transmitted beam is measured. This results in an analog signal which is then converted to digital form by an analog-to-digital converter and stored by a digital recording device.

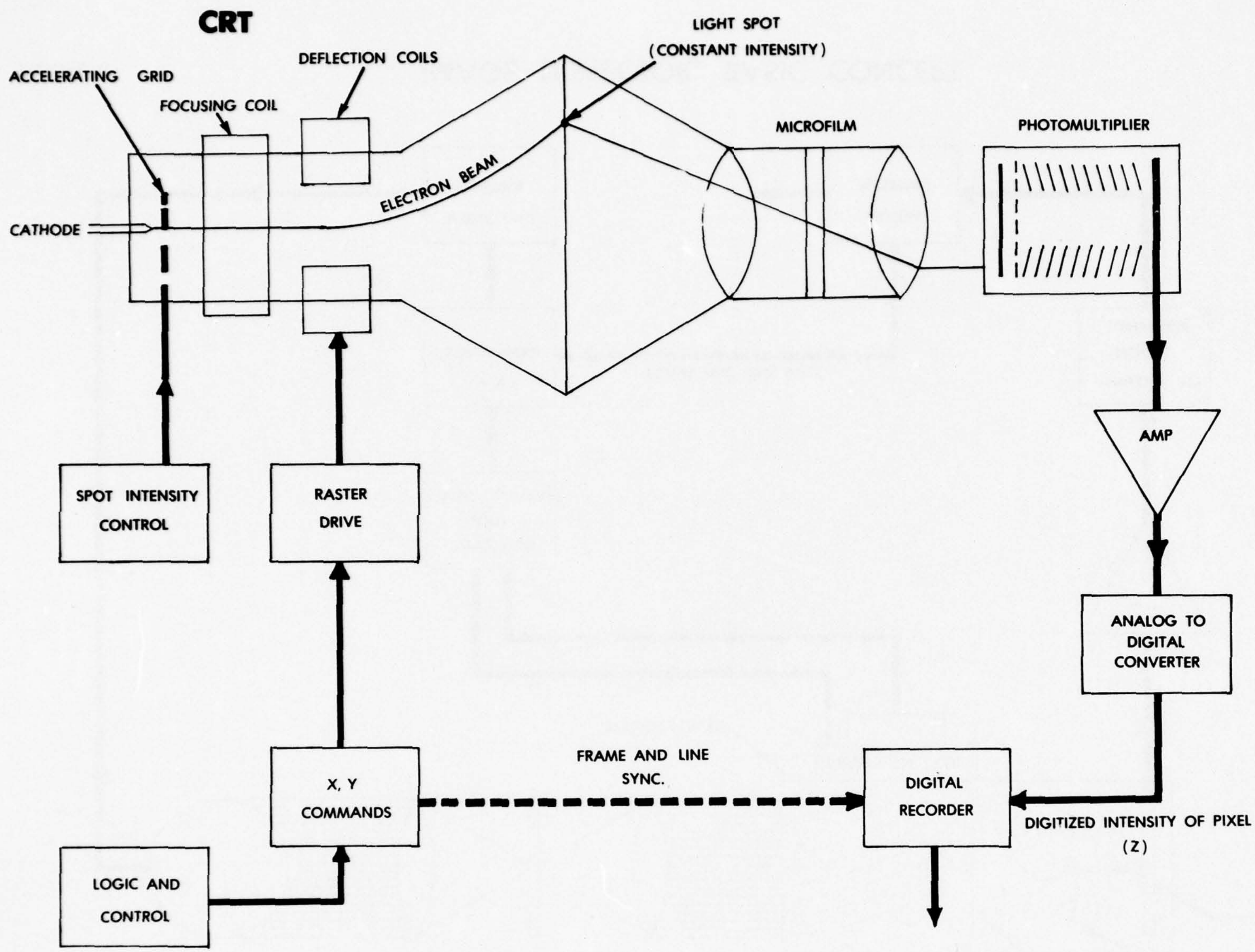

FIGURE 2. FLYING SPOT SCANNER, BASIC CONCEPT

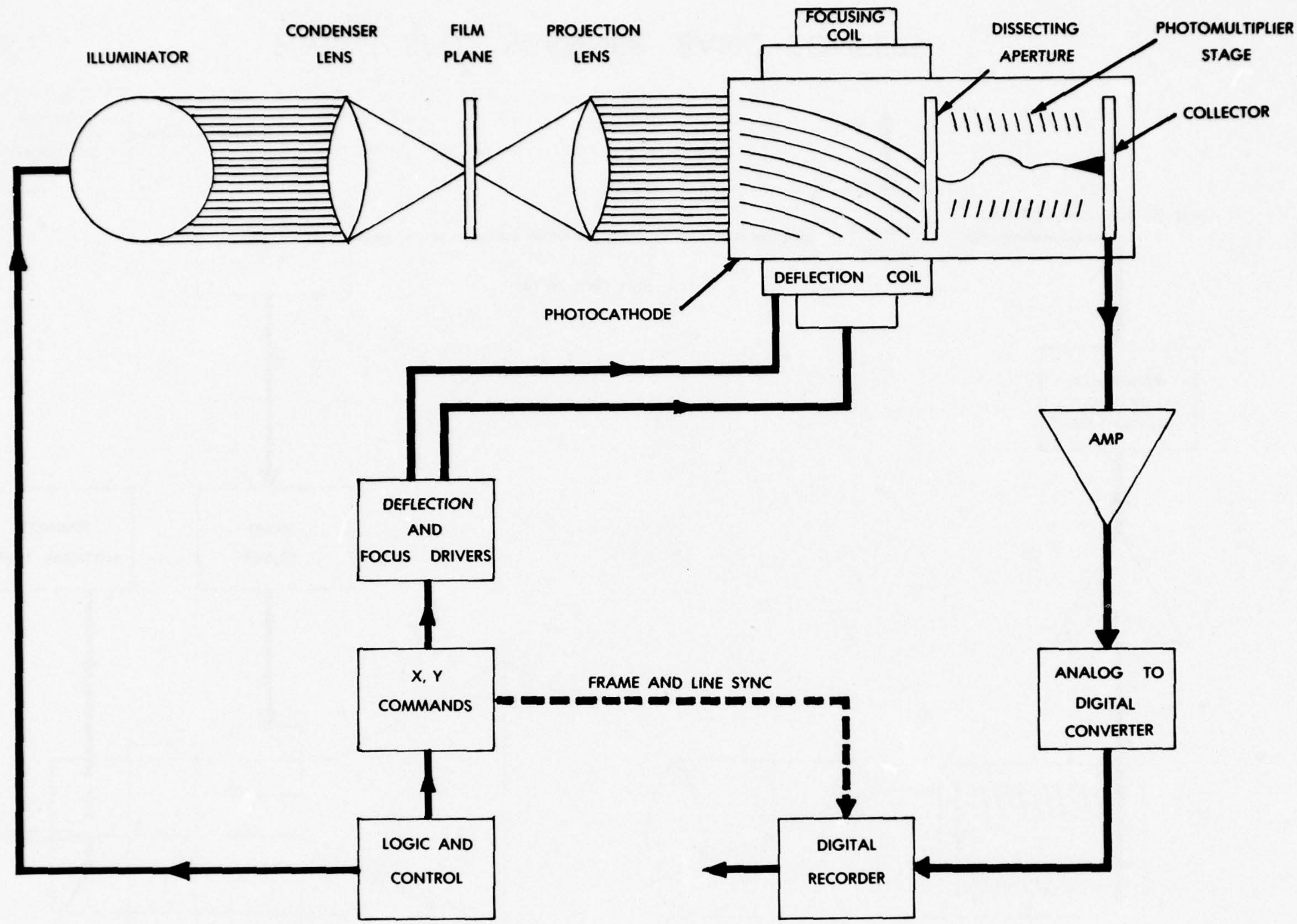

FIGURE 3 IMAGE DISSECTOR, BASIC CONCEPT

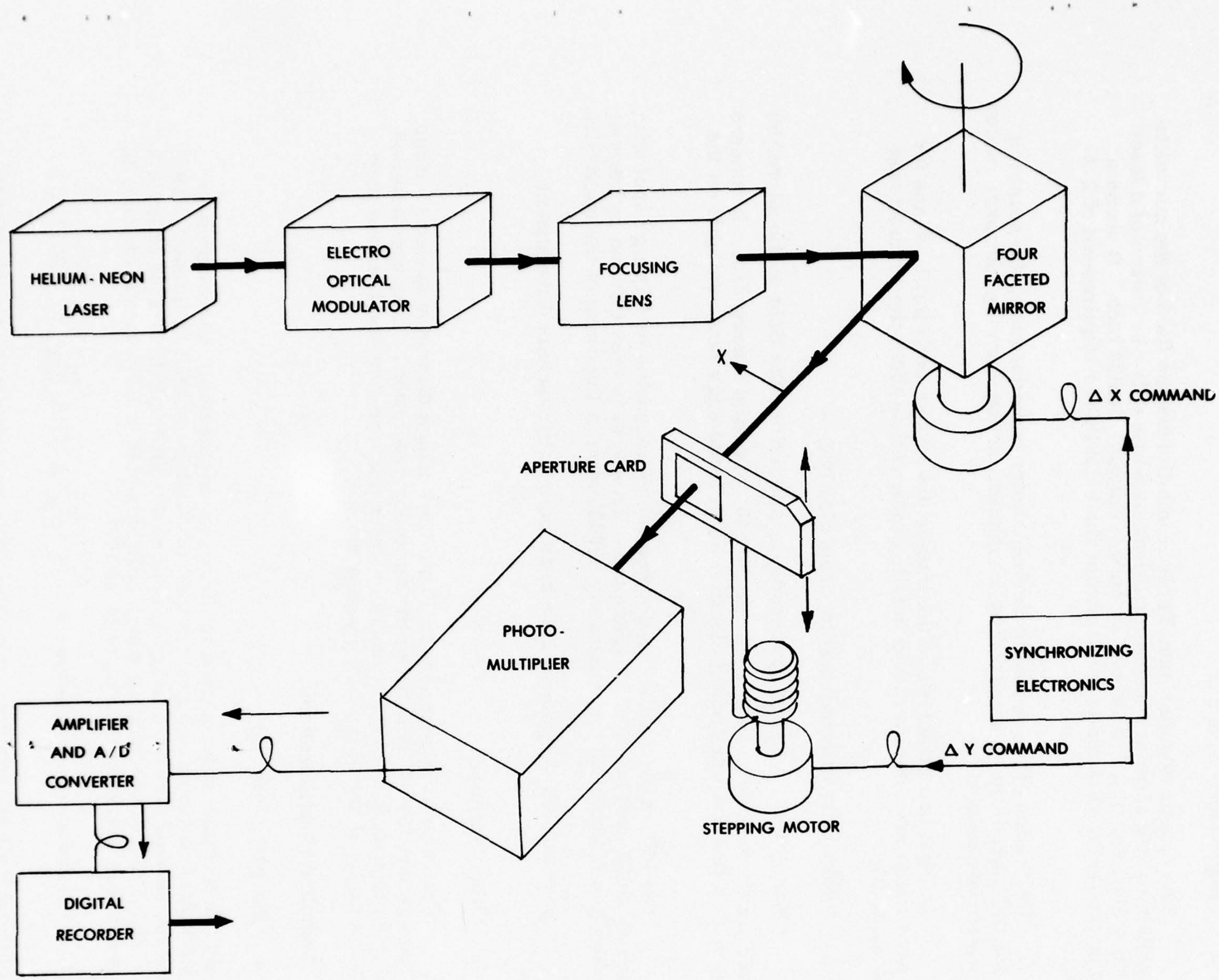

FIGURE 4 LASER SCANNER, BASIC CONCEPT

3.1.2.3 Scanning Devices

a. Singer Laser Scanner

The Singer Scanner (see Table 1) subdivides the field of the microfilm into 82 million pixels of binary scanning (black or white only) by means of a laser beam with a diameter of 3.5 microns, or approximately .000138 inch. It scans a frame of microfilm in 45 seconds, well within the established requirement of 2.4 minutes.

Unlike the other scanning devices under consideration, the scanning pattern for the laser beam is achieved by mechanical action (moving mirrors) rather than by electronic means.

At least one prototype of the Singer device has been built. Plans for further production are unknown, and detailed information about the scanner was not made available.

b. Information International Incorporated PFR-3

The PFR-3, a flying spot scanner, subdivides the field of the microfilm into pixels which include grey shades, or 36×10^6 pixels of binary data. It appears to be the best of the scanners using electron beam technology now available on the market.

The PFR-3 uses a CRT to develop a programmable or "flying" spot with a diameter of .0006 inch on the CRT phosphor. This spot is then focused by conventional optics to a diameter of approximately .00025 inch in the plane of the microfilm.

Several PFR-3 systems have been bought by various Government agencies.

c. Other Scanners

The remaining scanners in Table 1 are image dissector systems. None of these approaches the ADDSRTS requirements for resolution. They are included in the table as examples of present image detector performance and because they account for a major share of the film scanner market.

3.1.2.4 Technical Considerations

a. Sampling Interval

By the Nyquist criteria used in electrical engineering, the image must be sampled at least a factor of 2 greater than the highest spatial frequency. This means that for an aperture card image contained within the MIL-M-9868 criteria for resolution of 7.1 lp/mm on drawing which approximates to 113.6 lp/mm on film, the number of samples would have to be at least 9377.

$$1.625 \text{ inches (maximum image window)} \times 25.4 \frac{\text{mm}}{\text{inch}} \times 113.6 \frac{\text{lp}}{\text{mm}} \times 2 = 9377.$$

This theoretical limit is, however, not achievable as shown by the work of Otto Shade [8] and should be multiplied by the Kell Factor which is typically 0.7.

SCANNING DEVICE	TYPE OF SCANNER	RESOLUTION PARAMETERS			SPEED PARAMETERS		
		MATRIX ELEMENTS (PIXELS)	SPOT SIZE ON FILM	NBS RESOLUTION (IN LINE PAIRS PER MILLIMETER)	PIXELS OR SPOTS / SECOND	SECONDS / FRAME	MINUTES / FRAME
SINGER MICROGRAPHIC SYSTEMS	LASER	10,500 x 7,800 (82×10^6)	0.138 MIL ON FILM	127 LP / MM	1.8×10^6 PPS	45	0.75 MINS
INFORMATION INTERNATIONAL INC. PFR-3	FLYING SPOT	6,000 x 6,000 (36×10^6)	0.25 MIL ON FILM (0.6 MILS ON CRT)	73 LP / MM	2×10^6 PPS	8	0.13 MINS
DICOMED D 57, OR D 58	IMAGE DISSECTOR	2,048 x 1,536 (3.146×10^6)	UNKNOWN ON FILM (0.5 MILS APERTURE)	25 LP / MM	0.028×10^6	112	1.9 MINS
EMR (SCHLUMBERGER) 658 A	IMAGE DISSECTOR	2,048 x 1,536 (3.146×10^6)	APPROX 0.9 MIL ON FILM (0.75 MIL APERTURE)	25 LP / MM	0.020×10^6	157	2.6 MINS
PHOTO DIGITIZER SYSTEMS PDS 200	IMAGE DISSECTOR	1,000 x 750 (0.75×10^6)	UNKNOWN ON FILM (0.5 MIL APERTURE)	12 LP / MM	0.10×10^6	7.5	0.12 MINS
CUSTOMERS REQUIREMENTS	NOT SPECIFED	10,500 x 8,000 (84×10^6) APPROX.	0.14 MIL ON FILM	113.6 LP / MM ON FILM AT 16x (7.1 LP / MM ON DWG)	$.56 \times 10^6$ PPS	144	2.4 MINS

TABLE 1

SCANNER PERFORMANCE SUMMARY

The work conducted by Singer Simulation Products [9] has demonstrated using microfilm of an E size engineering drawing that a matrix of 10,500 x 7,800 elements will provide a data stream of sufficient size to permit re-imaging back onto film. The fifth generation of duplicards from the re-image continues to satisfy the resolution requirements of MIL-M-9868.

b. Spot Size

The Nyquist Sampling Theorem assumes that the sampling spot has an infinitesimal width. For practical systems the energy distribution is typically Guassian shaped. If there is a significant amount of energy outside the midpoint between samples, the resolution will be degraded from those computed under the above formula.

Although there are cathode ray tubes with spot diameters of .6 mils at the half energy level, such spot sizes are obtainable only at the center of the CRT. Moreover, such small spots require fine grain phosphors such as P-11, which is used specifically for recording purposes. This phosphor has a very long decay time on the order of 10 μ sec, which makes scanning at a rate greater than 100,000 samples/sec impossible.

It is possible to build a CRT scanner which scans at a rate of 2×10^6 samples/second, and also a CRT that can scan 35mm film at a resolution of 80 lp/mm. Such a rate and resolution, however, cannot be achieved simultaneously with a CRT.

c. Signal-to-Noise Ratio

For anything but a perfect image, the contrast ratio of the microfilm decreases as the spatial frequency of image increases. It is, therefore, extremely important that the signal-to-noise not be degraded further by the scanning process.

It is well known that a small spot size on a CRT can be achieved only at the cost of decreasing the beam current and reducing the grain size of the phosphor. Both factors tend to decrease light intensity so that the amount of light passing through the film is likely to be a fraction of a microwatt for clear areas on the film. At a scanning rate of 2×10^6 samples/second, the required video bandwidth should be not less than 2 megahertz. The signal-to-noise ratio for such a wide bandwidth and an input of a fraction of a microwatt will be extremely poor, however, and will result in lack of legibility and a great loss of compression ratio.

3.1.2.5 Scanner Summary

In summary, it is unlikely that CRT Flying Spot Scanners can deliver even the performance indicated. Even if it were possible, these scanners would be unacceptable because they have insufficient resolution and signal-to-noise ratio. By contrast, several laser scanners have been built which can satisfy all these requirements. The resolution of a laser scanner is basically defraction limited. An added advantage of laser scanners is the superior signal-to-noise ratio. Even for a small laser of a few milliwatts, the amount of energy penetrating the film will be a factor of a 1000 higher than for the CRT. Moreover, the scanning rate is not limited by phosphor decay.

For the immediate future, the inputting of drawings from microfilm offers the best approach. Of the many advantages, the predominant features are:

a. Consistent size for scanning.

b. Consistent contrast.

c. Ready adaptability to automatic inputting and outputting.

d. Similarity of input and output devices (since microfilm will continue to be used for contract data packages).

A laser scanner similar in principle to that used by Singer in its R&D Program appears to be the most appropriate microfilm input device. Since such a scanner is not commercially available, a design and development project for the device, complete with automatic feed of aperture cards, is of prime importance and should be vigorously pursued.

3.2 DATA COMPACTION/COMPRESSION

Data compaction or compression needs to be applied to the digitized drawing data produced by the microfilm scanning device to reduce the storage requirements and decrease the transmission time.

3.2.1 Data Compression

An engineering drawing can be described digitally with sufficient resolution by approximately 80 million bits.

Data compression techniques employ a combination of various algorithms in order to develop an optimum technique for the broad range of engineering drawings. Some of the schemes utilized in data compression are described below.

3.2.1.1 Run-Length Encoding

Pictorially, a drawing is described by a matrix of white and black points. Starting in the upper left corner and moving to the right, a tally of the white and black points is kept. For example, if the first dot is white, each dot is examined and the counter updated for every white dot until a black one is encountered. The counter is stored in the first word of the data record. The counter is reset and the black dots counted until a white one is encountered. The count of the black dots is stored in the next word and the counter reset. The process is repeated until all the dots are counted. This method is very efficient if there are large white areas on a drawing.

3.2.1.2 Line-by-Line Comparison

Each row of the drawing matrix can be compared with the next row. If the rows are identical, only the first one is stored and a line count kept of the identical rows. When there is a change in the row, the line count is stored. The new row is stored and a new line count kept. The process is repeated for the entire drawing.

This method is efficient if there are wide lines and large white areas on the drawing. It is used by many computer companies for core dumps.

3.2.1.3 Broadstroke Masking

With this technique, the drawing can be scanned visually and the area of interest shaded or broadstroked with colored ink. The scanner can be programmed to scan only the broadstroked area.

This method reduces scan time as well as record size, but it requires manual handling prior to scanning. A similar method is used at the National Bureau of Standards.

3.2.1.4 Vectoring

In this method, the coordinates for the beginning and ending of a line are determined and stored. When plotting, the plotter pen or beam is put down at the beginning coordinates and moved to the ending coordinates, drawing the line as it goes.

This method is very efficient if there are long straight lines in the drawing, but a problem exists in programming the scanner to follow the lines. This method is used extensively for microfilm and paper plotters.

3.2.2 Summary

It is known that various private companies have made studies of data stream compaction techniques from rectangular raster scans. One company in particular has performed extensive studies regarding pixel size and effects on resolution. This company has also studied the interrelationship with compaction techniques to obtain the high resolution of the outputted data compatible with the minimum of stored data.

Very recent work (late 1975) by one company in data compression has demonstrated the ability to scan and digitize 10 engineering drawings (D and E Size) obtained from five different companies. A variety of algorithms was developed which resulted in an average of 1.5×10^6 bits per drawing. Also, this company has developed a software program to convert a raster scanned data stream into vectorized format. Using this program, the company has taken a page of an overhaul manual scanned in raster form, converted it to vector form and displayed it on a graphic art terminal. With a light pencil to perform deletions and insertions and controlled programming to rearrange components, a revised image was created and recorded on hard copy.

This work exemplifies the requirement to integrate graphic art subsystems into ADDSRTS and illustrates some of the potential of the whole system. For the ADDSRTS system, the Navy should obtain its own data compression scheme. The scheme procured should be one that can be translated into electronic solid state circuitry so that compression or decompression can be performed by a "black-box" unit similar to a MODEM.

3.3 OUTPUT DEVICES

The requirement for full size drawings was determined as being minimal and needed primarily for consideration of modifications and for actual revision work. This requirement can be met in two ways; through enlargement printing

from microfilm (hard copy printing), and through the use of a plotter which would constitute a part of the new drawing generating system.

The majority of output would be required to satisfy two basic needs: one, contract data packages which would comprise microfilm aperture cards; two, engineering and manufacturing support needs which would be met by visual displays.

3.3.1 Visual Displays

The majority of visual display needs can be met with Cathode Ray Tube (CRT) type devices. Because of the expected need for a large display area, laser projection devices were also examined.

3.3.1.1 Laser Projection

Laser projection units are commercially available on special order. Their use is normally in applications requiring a display area above the normal 19-inch diagonal used in CRT displays. Their high cost and lack of versatility (when compared with CRT displays) render them unsuitable for this application.

3.3.1.2 CRT Displays

There are many types of cathode ray tube (CRT) devices now in use for displaying graphic data. The basic CRT, in which an electron beam writes directly onto the viewing phosphor, has been upgraded to achieve resolutions of more than 1,000 vertical lines. The upper limit of resolution is determined by the speed at which the electron beam can "write" across the phosphor and by the persistence of the phosphor.

A storage tube can extend the resolution capability to roughly 2,000 vertical lines. In these devices, a "writing gun" is used to write on a storage mesh within the tube during a write cycle. "Flood guns" then generate electrons which pass through the storage mesh to the viewing phosphor during a read cycle. Depending on the amount of data or pixels to be written, the write cycle may take several seconds, during which time the face of the tube is blank.

Scan converters provide additional flexibility in the size and orientation of the display. These devices contain an internal CRT, a videcon or television camera, and a viewing CRT. This arrangement can be used to achieve a windowing or zoom capability, but the resolution is limited to that which can be stored on the internal CRT.

No practical CRT device can display the 80 million pixels of a digitized ADDSRTS drawing in a single view. In order to display this amount of data, a display subsystem is required. The display subsystem could use items such as a Tektronix 4014, a 19-inch interactive terminal (storage tube), or a Hughes 639, a scan converter with a 1,000 line TV monitor. In either case, the image would be retained on a moving head digital disc in compressed form. The decompressor located in the display area would incorporate a capability to zoom and window the image. Since refreshing the image is not required (other than in the scan converter), this would eliminate the need for the video disc, which for 1000 line resolution has a poor reliability record. Moreover, the disc, a standard computer peripheral, could retain 160 images for browsing capability. It is also important

the decompressor could be time-shared between displays.

3.3.2 COMPUTER OUTPUT MICROFILM (COM)

The need to convert the digitized drawing data to a microfilm image is commonly met by means of a COM device. The two most frequently used methods will be described below.

3.3.2.1 Direct Exposure by Programmed Light Beam

The direct exposure of the film to a light beam is one way of recording the drawing image on the film. The digitized drawing data are used by a program in the control computer to control a light beam, such as a laser. Depending on whether the data stream format is raster or vector, the light beam either exposes spots on the film or draws lines of exposure.

Control of the light beam is the critical part of this method.

3.3.2.2 Photographing Face of CRT

In this method, a camera is used to take a photograph of the drawing image that is projected on a CRT. The program in the control computer directs the electron beam in the CRT.

When raster scan data are used, a spot is plotted; when vector data are used, a line of light on the CRT screen is drawn.

3.3.2.3 35mm Microfilm Recorders

Two of the most advanced, and possibly the highest resolution devices commercially available, were examined. Significant details are as follows:

Information International Incorporated (III) FR-80 Precision Microfilm Recorder

This unit provides high-speed microfilm recording of computer output at high resolution. The FR-80 consists of a minicomputer that buffers and accepts digital data from magnetic tape or disk, a translator that processes the data, and an electro-optical system that records the data as graphical information on a high-speed, high-precision CRT display. The drawing on the face of the CRT is then photographed and recorded on 35mm or 16mm microfilm.

The cathode ray tube is a 5-inch recording CRT, having a programmable raster of 16,384 by 16,384 points (including grey shades); however, it is believed that approximately 6,000 x 6,000 addressable binary points are realistic.

The FR-80 produces output microfilm at an average estimated rate of one frame per 20 seconds. This estimate was provided by III personnel from experience in use of the FR-80 to reproduce microfilm of drawings of average density and complexity. The FR-80 has a nominal point-plotting rate of 100,000 bits per second. The print-plotting rate does not include omission of blank spaces.

Singer Micrographic Systems MS-7000 Computer Microfilm Plotter

The Singer MS-7000 used a high-resolution CRT face for recording on microfilm. The MS-7000 has a CRT with 16,384 by 16,384 addressable spot position and is able to resolve 4096 by 4096 elements. The MS-7000 plots at a rate of 250,000 points per second.

The MS-7000 has a photocomposition package called TEXT/6 which runs on the computer in the MS-7000. This package can set text or it can merge computer designs or digital imagery into visual graphics.

The MS-7000 comes equipped with basic software, including an operating system, a support library and applications packages.

It appears that the Singer MS-7000 uses the technique of photographing the drawing as it is recorded on the face of the CRT.

3.3.3 Summary

It is apparent that no commercially available COM, not even one with reasonable adaptation, is suitable for ADDSRTS. The laser scanner used by Singer in its R&D work was also used to output the data stream to reform the image. It is conceivable that the COM could well be a duplicate of the input scanner with a special unit for exposure of regular film or silver halide. Secondly, the device should be capable of functioning intermittently. Since images can be recorded intermittently, the film must be capable of being processed not only in batches but frame by frame.

3.4 MASS STORAGE TECHNOLOGIES AND SYSTEMS

The heart of the ADDSRTS system is the mass data store. Extensive review of current technologies and available systems was conducted. The significant details are as follows:

3.4.1 Mass Storage Technologies

The primary requirements for mass storage systems are: (1) an extremely high-density recording technique; (2) an automated means of accessing various tapes, slides, and film of whatever media is used. The several current approaches to high-density recording are discussed briefly below.

3.4.1.1 Video Magnetic Recording

This recording technique involves recording data by writing an FM signal on a magnetic tape in the same way that images are stored on tape for television broadcasting. Packing densities of approximately 1 million bits per square inch may be achieved, resulting in a need for 1 million square inches of tape to store a trillion (10^{12}) bits of data. Speeds of around 1,000 inches per second can be achieved with current tape drivers. Thus, rather heavy dependence on mechanical motion of the tape is involved in accessing the tapes.

3.4.1.2 Magnetic Recording

Some of the mass storage techniques available today employ magnetic recording. Recording on a magnetic tape allows for recording up to approximately 120,000 bits of data per square inch. This results in a need for approximately

8 million square inches of tape to store 10^{12} bits of data. Again, a problem exists in the mechanical motion required to move the tape to position it to the read or record head.

Magnetic recording was considered undesirable for several reasons:

a. It is susceptible to damage by extraneous magnetic fields (i.e., non-archival).

b. It would need to be in reel, cartridge or cassette form and would therefore require scanning along the length to locate addresses of various documents (i.e., long access time).

c. Repeated movement over record and read head would lead to degradation of the tape and pick-up of extraneous noise.

d. Read and record heads would require frequent cleaning.

e. There is no known automatic equipment with reasonable speed and reliability capable of handling the size and quantities required for moving reels, cartridges or cassettes to the read or record heads.

3.4.1.3 Electron Beam Recording

The spot size of an electron beam can be as small as 10^{-2} microns, an improvement over optical recording of 3 orders of magnitude. This could theoretically provide recording densities on the order of 10^{12} bits per square inch.

This technique was rejected for these reasons:

a. No equipment to utilize this technique has, to date, been placed in production.

b. Density of 10^9 bits/10 sq. inch target would require approximately 10,000 targets.

c. The cost is high at 10^{-4} cents/bit or approximately $1,000/target.

3.4.1.4 Solid State (Semiconductor) Recording

This technique stores the data in integrated circuit (IC) chips mounted on printed circuit boards (PCB). These chips can store up to 65K bits/chip.

This technique was rejected for these reasons:

a. Low density: 65K bits/chip requires approximately 1.5 billion chips (1.5×10^9).

b. Large volume and interconnection.

c. Large power requirements: 10^6 watts/10^{10} bits require approximately 10^8 watts or 100 megawatts.

d. High cost.

3.4.1.5 Magnetic Bubble Domain

The bubble domain memory is the electromagnetic equivalent of the electrostatic CCD (Charge Coupled Device). The bubble is a small magnetic region which can be moved by putting current pulses onto clock line and formed in the simplest manner along shift register or a track on a rotating disk. The advantage is that the manufacture of this device is a thin film process and as with integrated circuits, no additional wiring is required.

Bubble domain memories should come into general use about 1980; however, a small 32 kilobyte unit is due to be marketed in the spring of 1976[10]

This media was rejected for these reasons:

a. Its susceptibility to damage by extraneous magnetic fields (i.e., non-archival).

b. Its low density, 10^7 bits/sq. inch requiring 10^6 sq. inches of media.

c. The high cost.

d. Its unavailability commercially as a mass storage media.

3.4.1.6 Holographic Recording

This method of recording data involves causing a signal beam, which carries the information, to intersect with a reference beam at a preselected angle to produce a fine-structured interference pattern. This pattern is then recorded to form a hologram or data storage array. The coherent reference beam is made to intersect with a signal-carrying beam and the resulting hologram is written into a storage array. To read out the data, a reference beam is directed toward the hologram and a set of photodetectors is used to read the reconstructed data.

This technique was considered undesirable for several reasons:

a. It requires film or similar media for recording and for processing to fix the image.

b. It requires long-length scanning to locate addresses of various documents (i.e., long access time).

c. It requires reels or cassettes for storage.

d. There is no known automatic handling system.

3.4.1.7 Optical Recording

This recording technique is based on the principle that an optical beam may be focused upon a spot whose diameter is approximately equal to the wave length of the incident light. Thus, for light in the visible range having a wave length of approximately 1/2 micron ($.5 \times 10^{-6}$ meters), the possible recording

density is 10^9 - 10^{10} bits per square inch. But a distance of one or two diameters must be allowed between spots to make accessing possible. The possible recording density using this method is thus in excess of 10^8 bits per square inch. Assuming this figure is accurate, a trillion bits require an area of $10^{12}/10^8$ = 10,000 square inches of recording surface for storage. This technique is a vast improvement over both video and standard magnetic recording. Currently, this method of recording and reading data is employed in systems which use a weak laser beam as the light source. Generally, no erasure is possible with this recording method.

This technique is considered to offer the best practical solution for the mass storage media. Equipment is commercially available and has been in operation for several years. However, two factors must be heavily considered:

a. The relatively high initial equipment cost, plus a high annual and maintenance cost.

b. The high power requirements; for approximately 2 1/2 million drawings on-line the power required is:

8200 CFM cooling air
6 GPM cooling water
201 KVA AC power, 208V-3PH

3.4.2 Mass Storage Systems

Four of the major mass storage systems reviewed are described below and details are tabulated in table 2.

3.4.2.1 Ampex Terabit Memory (TBM) System

The Ampex TBM system provides a complete system for storing data of approximately 10^{12} bits on-line. The system uses the video recorder technique to store data on reels of standard video recording tape, each of which contains over 40,000 user inches of 2-inch wide tape, allowing for storage of 44 x 10^9 bits on one video tape.

The TBM system has two main sections, the control section and the memory section. The control section contains the TBM system control processor, usually a PDP-11 minicomputer, and the interface buffers and multipath switching matrix which serve as the staging controllers for the system. The memory section contains three components: the transports, the transport drivers and the data channel units. These are described more fully below.

TBM Control System

a. System Control Processor

This component manages the read and write requests from host or peripheral units. Data are transferred to the host device by way of the interface buffers which enable data transfer to or from a host device.

EQUIPMENT	SECONDS ACCESS TIME MIN	AVG	MAX	COST CENTS/BIT	TOTAL MAX STORAGE CAPACITY	ERASABLE	LIFE EXPECTATION OF MEDIA	MEDIA TYPE
AMPEX TBM	5.45	21.6	50.4	.0002	3×10^{12} BITS	YES	20 YEARS	VIDEO TAPE
PRECISION INST. SYSTEM 190	.2	3.2	10.25	.00016	LIMITED ONLY BY THE # OF 191 UNITS THAT CAN BE HANDLED BY HOST COMPUTER	NO	INDEFINITE	LASER RECORDING ON RHODIUM STRIP
GRUMMAN MASSTAPE		6	11	.00012	$.67 \times 10^{12}$ BITS	YES	15 YEARS	HIGH DENSITY MAGNETIC TAPE
IBM 3850	UNAVAILABLE			10^{-6} CENTS / MONTH PER BIT	3.7×10^{12} BITS	YES	UNKNOWN	MAGNETIC TAPE CARTRIDGES

TABLE 2 COMPARISON OF MASS STORAGE SYSTEMS

b. Interface Buffers

These units provide the interface buffering required to transfer data between TBM and the user or host device.

TBM Memory Section

a. Transport Module

This is the basic storage unit, housing two tape transports and storing a total of 88 x 10^9 bits of data.

b. Transport Driver

This unit contains the electronic control for the transports. The transport driver is controlled by a minicomputer which handles all transport and data read/write activities.

c. Data Channels

These units contain the data electronics which handle independent, simultaneous read/write operations.

The maximum data capacity of the Terabit Memory System is approximately 3 x 10^{12} bits, using a full complement of six transport drivers, 32 transport modules, and three data channels.

With a file structure that makes almost complete use of the storage space, access times of approximately 21 seconds can be expected for random retrieval.

The advantages of TBM include its ease of interfacing and its built-in mechanisms for statistical analysis of file usage.

3.4.2.2 Precision Instruments System 190 Laser Mass Memory

This system uses a laser beam to read and record data on polyester strips onto which a thin layer of rhodium has been sputtered. To write on the strip, the laser beam forms a pattern in the surface of the strip which changes the reflectivity of the metallic surface, resulting in the formation of a digital binary bit pattern. The strip may then be read by accurately focusing a weak laser beam on each bit position. The reflected light is monitored and the intensity of the reflected beam allows the originally recorded data to be converted back to a digital bit stream.

The basic storage unit in the System 190 is the data strip, which has a capacity of 1.6 x 10^9 bits of user data. These data are recorded on 10,125 tracks on the data strip, each track containing 20,400 eight-bit user bytes. The smallest addressable storage section on the data strip is an 83-bit sequence called a clockword. Of the 83 bits in a clockwork, 64 bits are user space, while the rest are used for sequencing and error detection and correction. Thus, the smallest data record that can be used is a clockword, and any data record must have an integral number of clockwords.

The System 190 consists of three basic components: the 191 Control Unit, the 192 Read/Write Unit and the 193 Read-Only Unit discussed below:

Model 191 Control Unit

The Model 191 Control Unit is a programmable controller which provides logical control and monitoring of operation and direction of the 192 and 193 units. It also provides the physical interface to a host computer or other peripheral in the system configuration. Housed within the 191 Control Unit is a data buffer which acts as a temporary storage device and compensates for differences in speed between the System 190 and the equipment to which it is interfaced.

Each 191 controller can provide control for up to eight 192 or 193 units and provides for simultaneous search, load and unload operations.

Model 192 Read/Write Unit

The Model 192 Read/Write Unit uses a precisely controlled laser beam to record or read data on the drum surfaces, where the data strips are locked into place. The 192 contains a microprocessor, which is connected to the control bus of the 191 Control Unit. The 192 bus has a unique device address and can receive or send information along the bus. The 192 microprocessor receives a command and an address from the 191. The 192 then executes its internal hardware routines to select the proper data strip, unload the old data strip, load the new data strip, find the track address, and send data to the 191 controller.

Model 193 Read-Only Unit

This unit is identical to the 192, except that the recording laser and the laser modulation and control assemblies are removed.

A complete set of eight 192 or 193 units provides a total data storage capacity of 1.024×10^{12} bits.

Operation of System 190

The operating characteristics of System 190 are:

a. Maximum data strip load time from off-line is 60 seconds.

b. Maximum access time to unload, select, and load a new strip on the drum is 10 seconds.

c. The access times when the strip is on the drum are 250 milliseconds maximum and 220 milliseconds on the average.

3.4.2.3 Grumman Masstape

The Grumman Masstape system uses the high-density magnetic tape recording method. Data are recorded on 1/2-inch tape with a density of 8,000 bits per inch on 16 tracks. The tape is housed in cartridges, each of which contains 280 feet of tape providing a total of 2.4×10^8 bits. Eleven cartridges are contained

in one Masstape Pac. Four Pacs make up a drive which is brought in contact with one loader and recorder. Eight of these drives are then brought together to make up a storage unit with a total capacity of 8.4×10^{10} bits. Up to eight storage units may be combined for a total system capacity of 6.7×10^{11} bits.

The Masstape system has good access times. Average access to a single record in 6 seconds. The maximum access time is 11 seconds. However, the lowest addressable storage level is 11.5 million bits, with a tape speed of 150 inches per second.

3.4.2.4 IBM 3850 Mass Storage System (MSS)

The IBM 3850 Mass Storage System provides a large storage capacity that can interface with IBM computers and disk packs. The total system capacity of the 3850 is 472×10^{9} bytes or 3.7×10^{12} bits. Data in the MSS are stored in data cartridges on magnetic tape. Each data cartridge contains up to 4×10^{8} bits of data.

The IBM 3850 MSS operates on the basis of staging and destaging of data between the storage facility and the standard IBM 3330 disk packs. Commands are issued to read or write from 3300 disk, and the operating system shifts control to the 3850 controller which stages data to the 3330 disk drive. The host IBM computer then reads or writes data on the 3330 disk as it normally would.

No information could be obtained pertaining to IBM 3850 data access times.

Table 2 presents comparative data on the mass storage systems described above.

3.4.3 Summary

Review of the various technologies indicate that solid state, magnetic bubble domain, electron beam and holographic recording are not practical and suitable at this time for use in ADDSRTS. Magnetic recording, including video, is also considered unsuitable for three main reasons: (1) the recording media is considered non-archival; (2) the quantity of reels, cartridges or cassettes likely to be required make it impracticable to provide on-line capability; (3) experience with electro-mechanical devices indicates that extensive design and testing would be required to provide automatic equipment for moving reels, cartridges or cassettes with reasonable speed and reliability.

Because it is fully automatic and archival, the laser beam recording on metallized strips offers the best solution. Despite the two negative factors, high initial and maintenance costs and high power requirements, with R&D effort a major breakthrough can be made in this much needed area of high density mass storage. It is recommended that such an effort be vigorously pursued, not only to provide a sound cost effective mass storage for ADDSRTS and for other military uses, but also to meet the critical needs of commerce and industry (3).

3.5 DATA TRANSMISSION AND TECHNOLOGY

In order to meet the ADDSRTS objectives, the digitized drawing data in the compacted form must be transmitted at speeds of at least one megabit/second.

The important features to be considered are:

3.5.1 Transmission Line Technology

a. Operating Bandwidth

Since the transmitted waveforms are rectangular rather than sinusoidal, the transmission lines must be capable of passing the predominant Fourier components of the rectangular wave form in order to avoid serious distortion of the data pulses. As a rule of thumb, the bandwidth of the transmission line in generally specified as at least twice the band rate for rectangular pulses. Consequently, the required operating bandwidth of these lines must be at least 2 MHx.

b. Prime Considerations

In this application, the factor which will have the greatest effect on reliability are attenuation, reflections, and induced noise.

Attenuation:

At high frequencies, attenuation losses are caused primarily by skin effect, rather than the steady state of dc resistance of the conductors. The attenuation, expressed in dB per unit length of cable, varies as the square root of the frequency. For cable lengths of 1,000 feet, operating in 2MHz range, attenuation can vary from 1 dB to several hundred dB, depending on the choice of cable. For any given ambient noise level, attenuation decreases the signal-to-noise level and therefore degrades reliability and performance.

Reflections:

In the MHz range, it is important that the characteristic impendance of the cable be constant throughout the length of the cable, and that the cable be terminated with this same value of impendance. Discontinuities in the impendance of the cable will cause reflections that degrade performance. The characteristics impendance of any given cable is determined by the spatial relationship between conductors and the properties of the intervening dielectric material. In coaxial cables, these relationships are carefully controlled during manufacture. Large coaxial cables are relatively immune to normal manufacturing errors or damage from physical handling. Small diameter coaxial cables are more vulnerable to such conditions and are therefore intrinsically less reliable. For conventional twisted pair cables, the characteristic impendance is, for all practical purposes, uncontrolled; therefore, undesirable reflections must be anticipated.

Induced Noise:

Cables are susceptible to noise induced by adjacent electromagnetic fields. This effect can be minimized by single or double shielding or by the use of "balanced" coaxial cables which contain two adjacent conductors within an outer shield.

c. Typical Characteristics of Cables

In general, the conventional twisted-pair cable used in telephone lines is not in keeping with good engineering practice. As previously stated, the high frequency characteristics of such lines are uncontrolled. The Attenuation of 28 AWG wires of 2 MHz is more than 120 dB/1000', at least an order of magnitude greater than the cheapest available grade of outdoor coaxial cable.

RG11A/U coaxial cable has an outer diameter of 0.412 inches. The retail cost is $263.85 per 1,000 feet. Attenuation of 2MHz is 30 DB per 1,000 feet.

RG218/U coaxial cable has an outer diameter of 0.880 inches. The retail cost is $2,020 per 1,000 feet. Attenuation of 2MHz is 0.9 dB per 1,000 feet.

RG219/U coaxial cable is equivalent to RG218/U but has an additional outer shield of braided aluminum wire. The retail cost is $2,850 per 1,000 feet.

3.5.2 Transmission Lines (Short Haul) on Station

As previously stated, a good grade of coaxial cable, such as RG218/U or RG11/U, should be used for the high-speed transmission lines. An alternate choice would be twin-conductor coaxial cable, such as RG57A/U, RG130/U or RG131/U. These cables permit a balanced or "push-pull" mode of transmission which would virtually eliminate the susceptiability to external fields and variations in ground potential between the various sites.

A secondary channel, half-duplex or duplex, using common voice grade lines, is recommended to support the operation of the high-speed channel.

3.5.3 Transmission Line (Long Haul) to Other Activities

In planning the overall system, intercommunication between other Navy activities, including ships at sea, has been considered as possible long range objectives. Existing technology and equipment are capable of providing this degree of sophistication now, and the design concept of ADDSRTS is fully compatible. Although such tie-ins would be highly desirable and would greatly improve overall efficiency, this interconnection was not examined in great depth because such determination should be based on need or cost effectiveness.

Examination reveals that solely for document transmission, a voice grade line with suitable modems could transmit a drawing in approximately 1 1/4 minutes. Document research, as well as other demands, though an interactive terminal might well require higher speed transmission to be effective and consequently higher costs for high speed data transmission lines and modems. Another consideration is whether common carrier should be utilized or the military communications network.

3.5.4 Data Modems

Most modem devices now on the market are intended for use with commercial, leased or private voice grade lines, and are therefore limited to data rates of less than 20,000 bits per second. The smae constraint applies to Electronic Industries Association Standard RS-232-C (Interface Between Data Terminal Equipment and Data Communication Equipment).

A limited number of devices classified as "short haul" modems deal with special problems of transmitting data in the megabit-per-second range over distances of roughly one mile. One such device is the International Communications Corporation Modem 1100, which transfers data at rates up to 1 million bits per second over coaxial cable runs up to 2.4 miles.

Another family of devices is oriented toward data transfers between two computers at the maximum rate possible. The HP 12889A Hardwired Serial Interface is representative of this category. This device transmits data asynchronously up to 1000' at 2.5 million baud, or up to 2,400 feet at 1.25 million baud. The catalog cost of this device is $750. This family of devices appears to give the best fit to the ADDSRTS requirement. Interfacing problems would be minimized if such a device were procured as an accessory to the computer selected for ADDSRTS, and if it were designed for direct connection to the computer I/O parts.

As previously stated, a hardwired serial interface similar to Hewlett-Packard Model HP 12889A will meet the requirements for a high-speed modem. Since all high-speed transmissions will emanate from only two ADDSRTS stations, the scanning station and the mass storage station, a simplex mode of operation for the high-speed channels appears prudent. Such a model will simplify the protocol functions of the modems.

SECTION 4

RELATED PROJECTS/PROGRAMS AND INTERFACE

4.1 INTERACTIVE GRAPHICS

Under the Manufacturing Technology (MT) Program, work in the field of interactive graphics should commence in early 1976. The intent of this work is not to conflict with the graphics portion of ADDSRTS but to complement it by determining the feasibility and usefulness of an area more directly related to manufacturing. The objective is to explore its effectivity in such areas as verifying and modifying N/C tapes, preparing tapes for N/C cutting machines and coordinate measuring machines, as well as developing tolerance charts and manufacturing PC boards.

Through the examination of existing software programs and through various studies of their modification and utilization, it is hoped to broaden the application of the Graphic Art Sub-System within ADDSRTS.

4.2 GRAPHIC CODING OF PARTS

This project is currently funded under the MT program. The completion of the project will provide a graphic coding system for, as well the coding of, existing drawings. This effort will complement the indexing-file system of ADDSRTS not only by providing quicker access to existing parts but also in the various aspects of new design, elimination of duplication, and reduction of like components, tooling, etc.

4.3 AUTOMATED PROCESS SHEETS

This project was funded under the MT program and enabled the installation of a system of typing process sheets automatically with computer aided editing ability. This system is not expected to be directly related to ADDSRTS; however, it is a vital part of the family of automated manufacturing support systems.

4.4 DATA LISTS

Work is currently being performed by NOSL to update data lists and to process them through the Station's Data Processing Department to partially automate and improve the formulation of data packages. This on-going work, which includes software programs, can be incorporated into the indexing-file system of ADDSRTS to permit through the insertion of a single drawing number, or data list number, a listing and access to all referenced documents.

4.5 PUBLICATIONS AND MANUALS

Exploratory work is currently being done on the various methods of obtaining and assembling publications and manuals, as well as their revision and distribution. With suitable programming ADDSRTS can provide through the Graphic Art Sub-System the recall of drawings, three-dimensional composition, and isometric or infinitesimal projection, thereby greatly improving the method of preparing graphics for inclusion maintenance and parts breakdown manuals. Other programming should permit the merging of text with graphics.

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SECTION 5

ADDSRTS REQUIREMENTS

5.1 PRESENT FUNCTIONAL FLOW

The functional elements of the present document storage and retrieval system at NOSL are presented in the flow diagrams displayed in Figures 5, 6 and 7. As the figures indicate, there are six basic functional elements which are performed in conjunction with the Technical Documents Department (TDD), which is the central repository for engineering drawings, aperture cards and technical publications. The functions are briefly described as follows:

5.1.1 New Input

New documents to be added to the file are produced in-house by various drafting offices or are received from outside sources as part of a contractual obligation. These documents may be in original drawing form or film mounted in aperture cards. Originals are microfilmed in TDD, cataloged and indexed, and placed on file. Incoming aperture cards are inspected for such factors as quality and resolution, cataloged, indexed and added to the file.

5.1.2 Revisions

The master aperture card of the latest revision of the drawing on file, together with a drawing original, if available, are withdrawn and duplicated. The masters are returned to file and the duplicates are forwarded for revision action. After completion of the revision (by alteration to the drawing original or redrafting), the revised document (now an updated master), together with the revision directive, is forwarded for microfilming, filing and index updating.

5.1.3 Manufacturing Requests

The master aperture card is withdrawn. Depending upon the nature of the request, a duplicate aperture card is made and the master is returned to file, or the master is forwarded for hard-copy reproduction and returned to file.

Usually, aperture card duplicates are used for all manufacturing support functions, with hard copy usually for the production work package.

5.1.4 Engineering Requests

The master aperture card is withdrawn. Depending upon the nature of the request, a duplicate aperture card is made and the master is returned to file, or the master is forwarded for hard-copy reproduction and returned to file.

Usually hard copies at "C" size (22" x 34") are used for such purposes as design reviews and producibility reviews, with aperture cards for in-service engineering and technical support.

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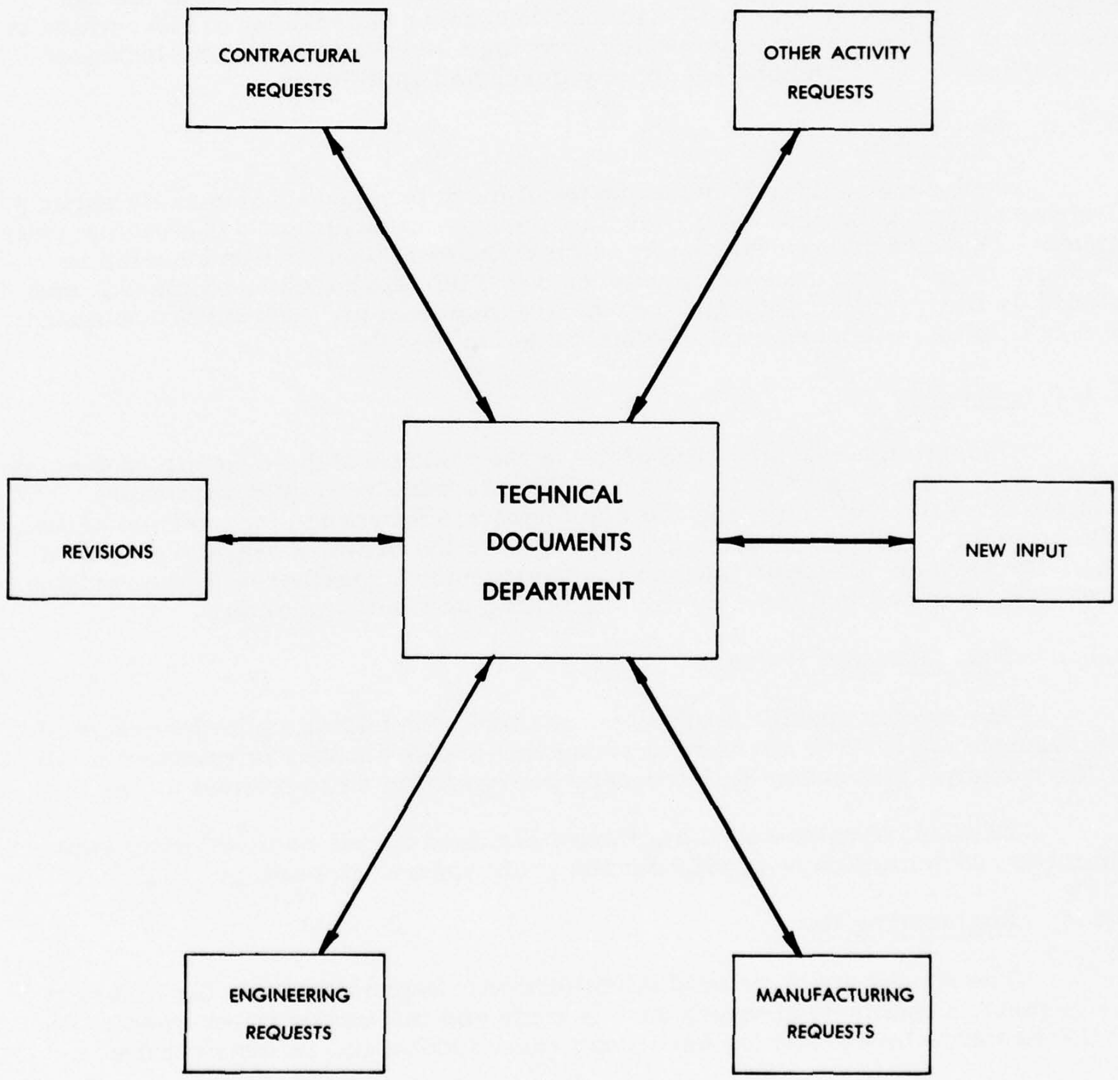


FIGURE 5

FUNCTIONAL FLOW DIAGRAM OF TECHNICAL DOCUMENTS

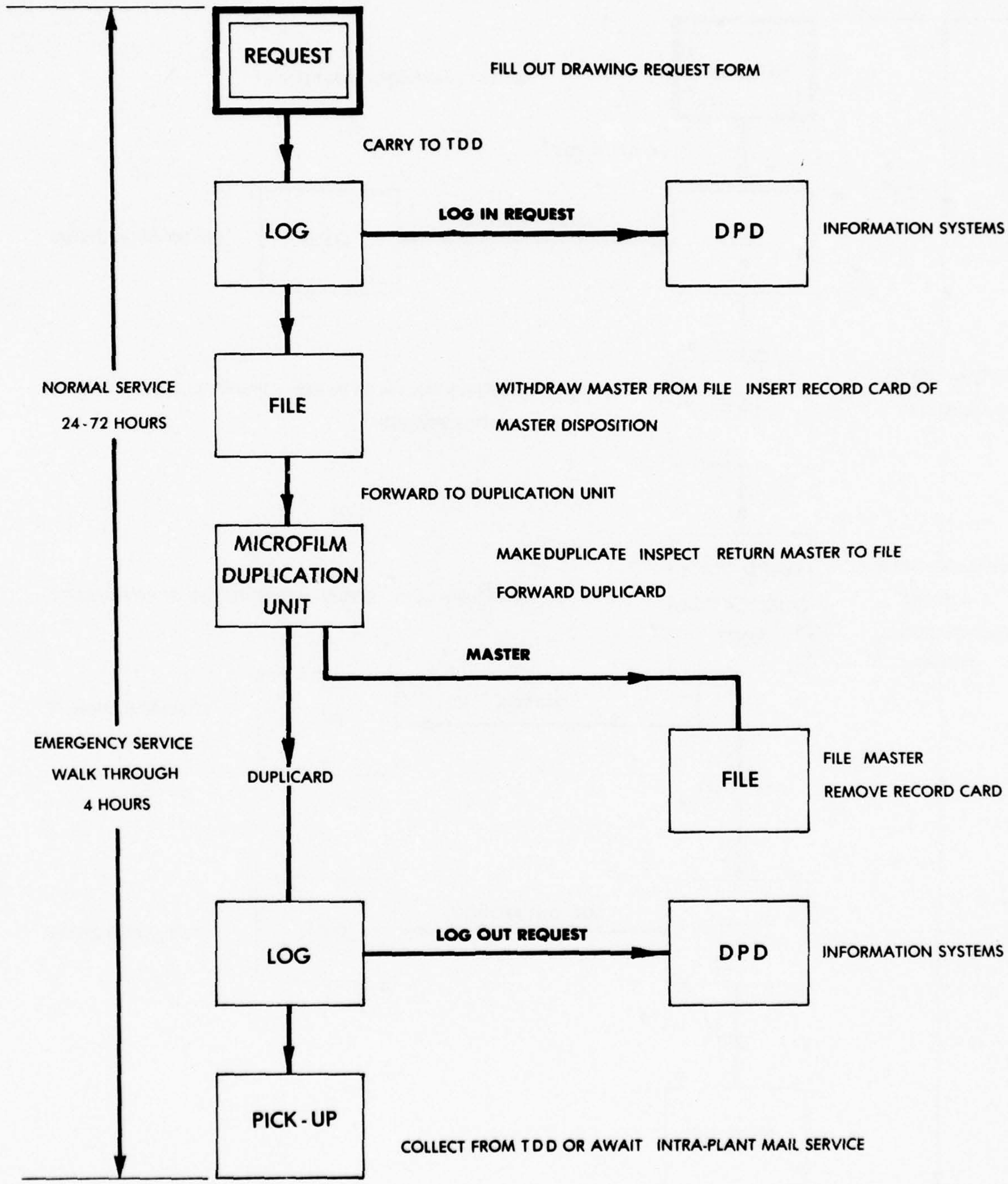


FIGURE 6 TYPICAL FLOW & ACTION FOR APERTURE CARD REQUEST

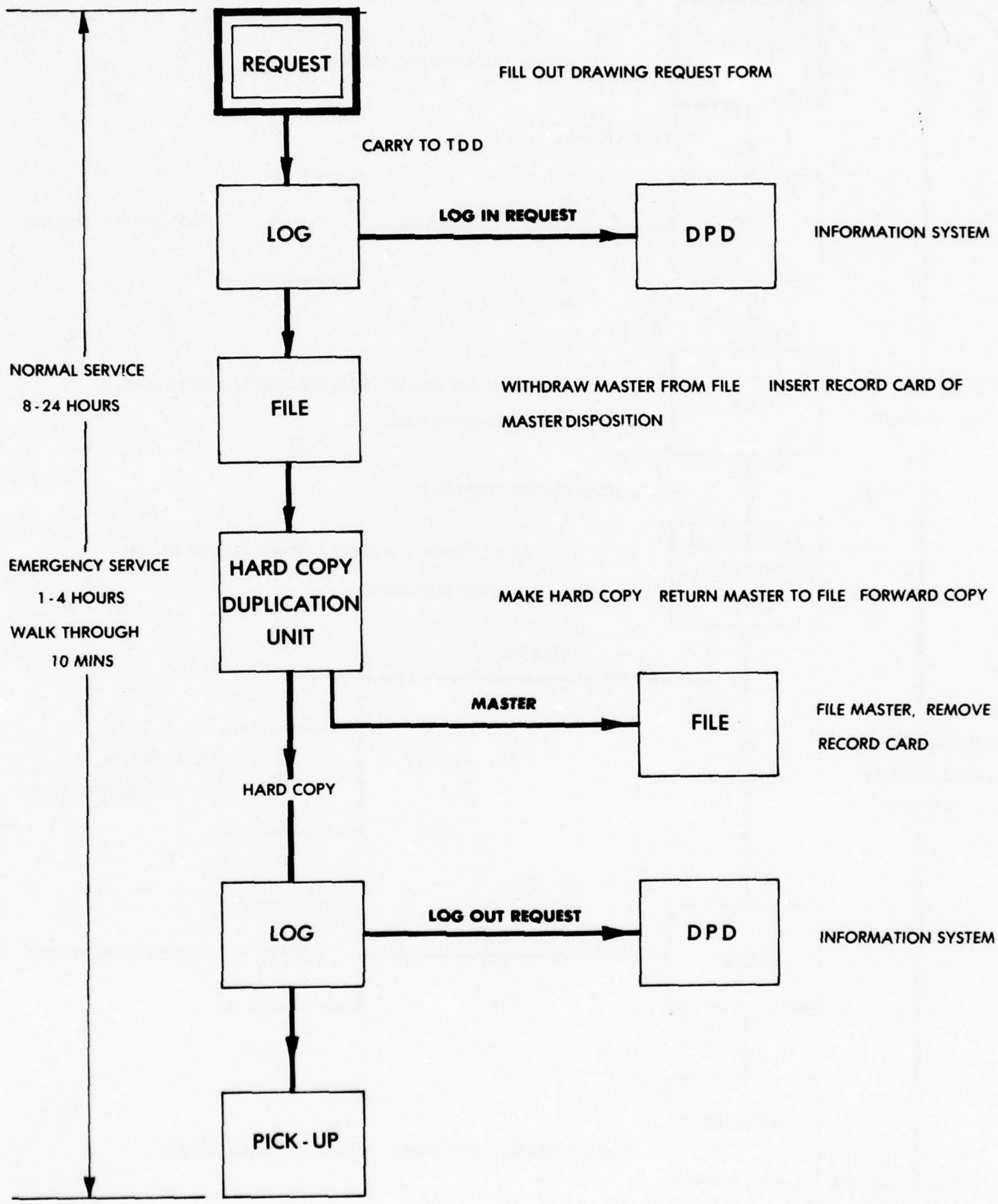


FIGURE 7 TYPICAL FLOW & ACTION FOR HARD COPY REQUEST

5.1.5 Contractual Requests

a. Contract Administration. These are often single requests for one or two documents, usually in hard copy for clarification of poor aperture cards.

The master aperture card is withdrawn and forwarded for hard copy reproduction and returned to file.

b. Contract Data Packages. These are usually requests for duplicate aperture cards, that is, for quantities ranging from a single document up to 35,000 documents when required for contract data packages (Invitations for Bid - IFB).

5.1.6 Requests from Other Activities

These are normally requests of single or multiple drawing numbers for aperture cards from various activities for engineering and support of weapons systems. The master aperture card is withdrawn from file, a duplicate card is made and the master returned to file.

In a number of instances, requests are unable to identify the drawing numbers. The request may be worded: Piston, hydraulic assembly, transfer tray on 5"/54 cal mount. In these instances, TDD personnel perform a search of service manuals, and other possible sources, to identify the appropriate drawing number.

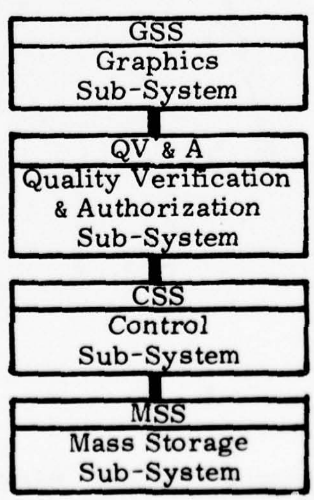
5.2 PROPOSED OPERATIONAL FLOW

The operational flow for each of the major functions is divided into subsystems as shown in Figure 8. The sub-systems, grouped into three phases as shown in Figure 9, could be implemented to produce a progressively built pilot system that would enable debugging and analysis in stages.

For the final phase, the acquisition of the remainder of the peripheral equipment would enable the total system to be installed and fully implemented.

5.2.1 Phase I - Pilot Vector Data Input System

It is proposed that Phase I be comprised of four sub-systems:



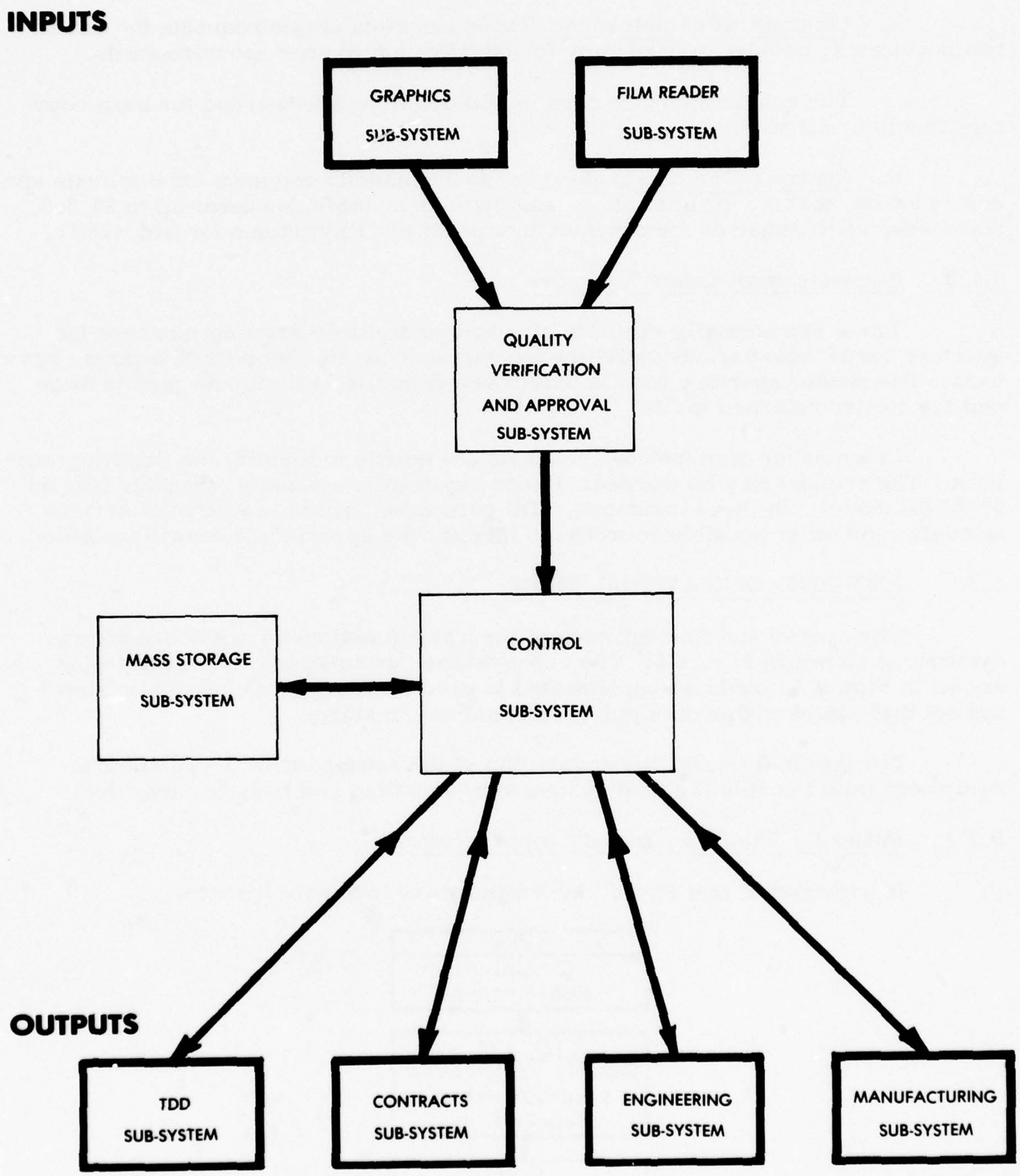


FIGURE 8 **ADDSRTS FLOW DIAGRAM**

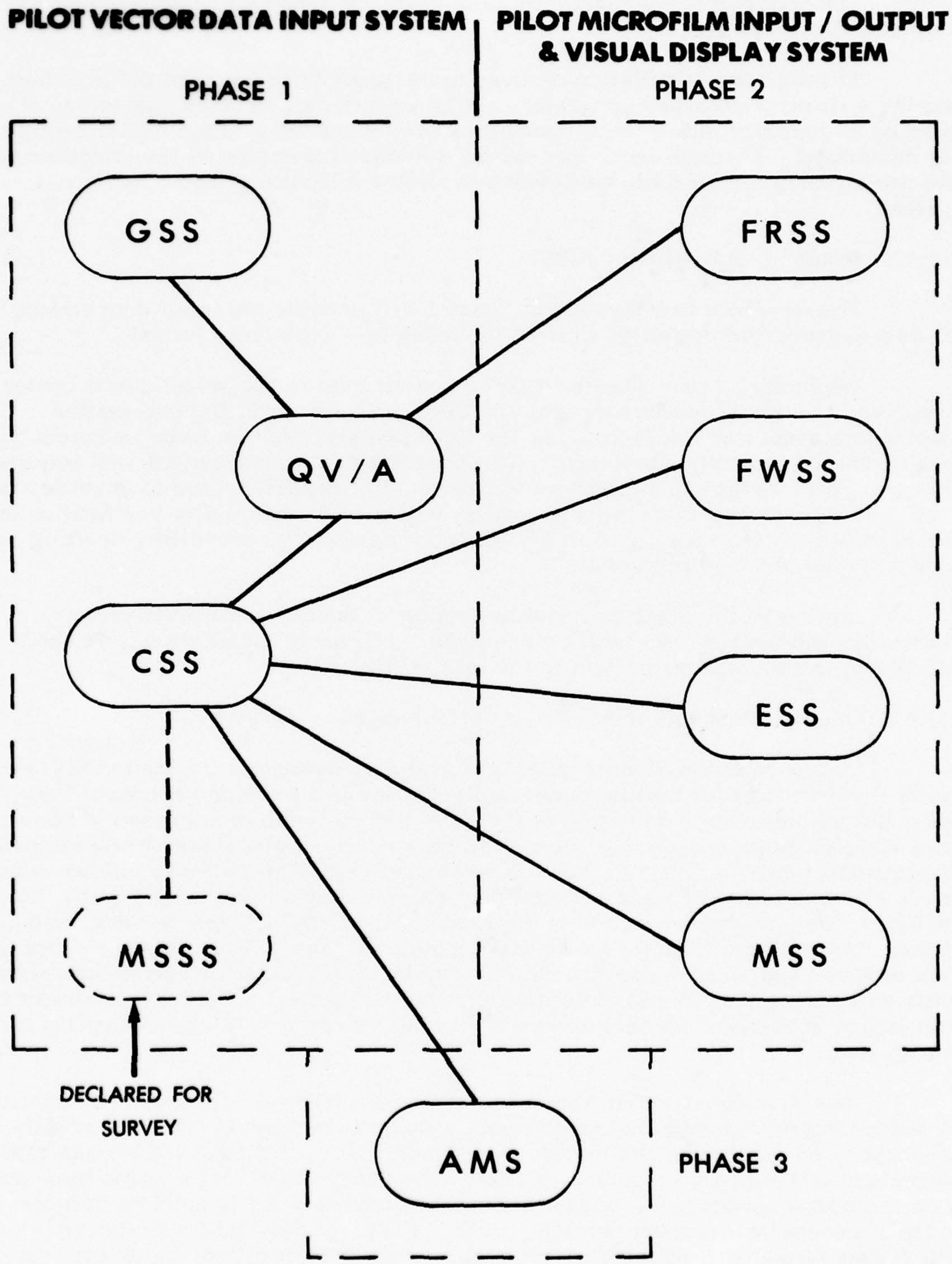


FIGURE 9 PILOT ADDSRTS SYSTEM

The majority of component units to comprise these four sub-systems are commercially available.

Through the installation of these units, the performance of the interface, and the writing of software programs, a pilot system can be made operative. The training of graphics sub-system operatives can be started and the initial debugging performed. Through use, data can be developed to establish the effectiveness and permit design criteria to be developed for the fully integrated operational system.

5.2.1.1 Graphics Sub-System (GSS)

The Graphics Sub-System in Phase I will provide the input data stream for new engineering drawings drafted in-house in a vectorized format.

Typically, a new drawing will be constructed in the graphic arts center comprised of a large screen storage tube display, keyboard, flat bed plotter, central processor, an electronic pen (or light pencil), and, in some instances, a programmable functional keyboard. The processor (mini-computer) will require disk and possible tape to support a zoom or window capability and to provide storage. The data stream from the sub-system will pass to the quality verification and authorization sub-system through MODEM's, if necessary, permitting drafting remote from the other sub-systems.

In view of the other projects in Section 4, considerable software programming, debugging, etc. will be required. The early installation of Phase I will permit a progressive growth to the total ADDSRTS.

5.2.1.2 Quality Verification and Approval Sub-System (QV/A)

The Quality Verification and Approval Sub-System is the station that reviews the drawings for completeness and accuracy and provides approval for document authentication on behalf of the Navy before the data is passed to storage. This stage essentially replaces the review by various engineering personnel prior to authentication. In Phase I, this sub-system will only be partially implemented, but it will enable the flow pattern and the design criteria to be established. Essentially, the sub-system will be a duplicate of the Graphics Sub-System, without plotter, but with a buffer (to act as intermediate storage). Completion of work on data compression and the construction of a solid state compactor and decompactor units will enable these units to be incorporated and tested. Software programs for conversion of raster scan data to vector form and vice-versa should complete the sub-system.

New data constructed within the GSS are composed in vectorized form and by software program may be transformed in rasterized format. The vector data are forwarded directly to the buffer. The raster data are forwarded via the raster compactor unit, upon command from GSS. The data in both forms are withdrawn from the buffer by the QV&A operator who performs detailed inspection and provides approval for document authentication. His inspection will also determine which data format will be used in the mass storage. In addition, he directs the buffer to dump to the CSS. When required, the GSS can withdraw data from the file via the CSS for review or update. Depending on stored format, the data stream will pass either directly to the GSS when in vector form or via the raster decompactor when in raster form.

5.2.1.3 Control Sub-System (CSS)

The Control Sub-System is the main computer controller. The primary function is that of performing the supervisory program which will monitor and control priority and queuing of random line requests, computer channel utilization, and file indexing and retrieval software.

It is predicted that buildup of this sub-system will take several years, primarily due to the demands of extensive programming and compilation of the file and indexing system. Through early installation of the basic hardware, the software programs can be tested and debugged in a progressive manner.

The full control sub-system will perform a queuing sytem which will permit the handling of simultaneous requests from up to 15 remote sites, output to a remote microfilm printer, batch output to two other microfilm printers, and control input to the system via the graphics subsystem and microfilm input scanners. The control sub-system will be able to handle a time-sharing operation and a batch operation. It must be capable of handling a minimum of 16 input-output channels.

The core size for the control sub-system shall be capable fo storing and operating the time-sharing systems. the applications software which will perform, seek and retrieve, and to perform search routines.

The sub-system is supported by disk and magnetic tape storage, which will provide the full index.

5.2.1.4 Mass Storage Sub-System (MSS)

The Mass Storage Sub-System will be the repository for the data describing the engineering drawings and other referenced documents, such as data lists, etc.

In Phase I, it is proposed that one complete System 190 be used for mass storage. The System will be comprised of three units: #191 Controller, a #192 Read/Write Unit, and a #193 Read Only Unit.

a. The controller will provide the logical control and monitoring functions required for operation and direction of the 192 and 193 units. The unit houses the data buffer which acts as a temporary storage device and compensates for the difference in rate of flow of data between the System 190 and the Control Sub-Systems to which it is interfaced.

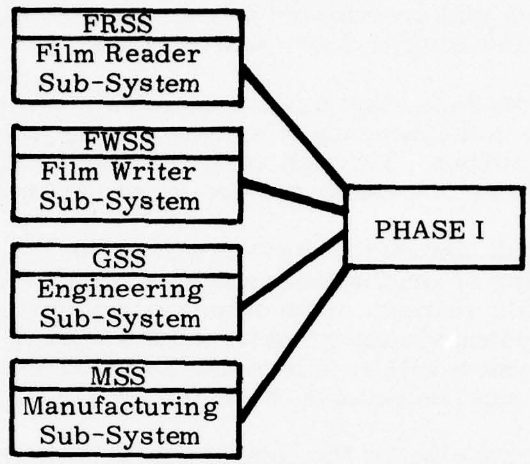
b. The read/write unit, the recording unit of the sytem, can also read previously recorded data. This unit has a storage capacity of approximately 160,000 engineering drawings.

c. The read only unit will provide additional document storage capacity for 160,000 engineering drawings.

It is recommended that one System 190 be procured in Phase I to establish a pilot system. This will complete the cycle from input to store and back to output.

5.2.2 Phase II - Pilot Microfilm Input/Output, And Visual Display System

This phase will be comprised of four sub-systems:



The engineering and manufacturing systems will be basically visual display terminals, with the majority of component units commercially available. The film reader and film writer sub-systems will require the specific design, development and test for ADDSRTS.

5.2.2.1 Engineering Sub-System (ESS)

The Engineering Sub-System will be similar to GSS but without the flat bed plotter. Additional software programs are planned for these terminals to provide finite element analysis, other design analysis and simulation.

5.2.2.2 Manufacturing Sub-System (MSS)

The Manufacturing Sub-System will be similar to the ESS. Software programs particular to manufacturing engineering and control will be the basic difference. Through the installation of an ESS and a MSS full design, utilization and effectiveness can be determined.

5.2.2.3 Film Reader Sub-System (FRSS)

For the Film Reader Sub-System (the input terminal for existing aperture cards), the major thrust will be the design, devleopment, building and testing and installation of the unit. Utilization of existing technologies will provide the laser scanning and translation, modulation, etc.; however, considerable design effort will be required to provide suitable automatic feed for aperture cards. Following installation, detailed testing and anaylsis will be conducted of the various aperture cards of drawing and other documents in conjunction with the compactor and programs to convert raster scan to vector format. The data obtained will provide factual support to enable decisions to be made on final size of such items as mass storage, costs, together with design criteria regarding type of data stream stored (vector, raster or both).

5.2.2.4 Film Writer Sub-System (FRSS)

The Film Writer Sub-System (the output terminal for reimaging on microfilm aperture cards) is envisaged as primarily a duplicate of the Film Reader Sub-System. It is hoped that the design of the film reader unit will provide a basic unit that can be used with different attachment heads. Therefore, the primary work will be the design, development, building and testing of the attachment or a duplicate unit for the exposure of film or silver halide. The attachment should also be capable of functioning intermittently so that images can be recorded singly or in batches, which in turn will permit final processing on an as-needed basis.

5.2.3 Phase III - Advanced Mass Store (AMS)

The implementation of the full ADDSRTS system using System 190 units for mass storage is possible but not practicable, primarily because of the electrical power required and the high maintenance cost projected. The technology for high density optical recording on metallized films is an established fact as an archival medium (as demonstrated by the System 190). Examination as a result of this study has shown the desperate need for higher storage capacities within smaller volumes.

Patents exist for an advanced mass storage capable of storing 2×10^2 bits on 200 slides in the form of a carousel within a space approximately 2 1/2 ft cube. Further discussion on the details of this portion are withheld to maintain to proprietary information restricted.

However, the development of this major advance is considered of the utmost importance not only to the effectiveness of ADDSRTS but also because of its paramount significance for other military and commercial systems. It is, therefore, recommended that a Phase III be devoted to an R&D effort to produce an advanced mass storage unit.

When the unit is completed and installed, final testing and evaluation will be conducted. With minor software program modification, it is proposed that it replace the System 190. It would then be interconnected to the other sub-systems as shown in Figure 9. With this arrangement, a full pilot of the total ADDSRTS would be operational. This would then enable final design of the total ADDSRTS system.

5.2.4 Phase IV - Full ADDSRTS Implementation

The effort of this phase will be to analyze and evaluate the data obtained by the installation and operation of the sub-systems of Phases I and II and by the pilot ADDSRTS system assembled in Phase III. From the evaluation, a determination will be made on the balance of sub-systems and units required for full implementation.

During the acquisition of the remaining equipment, the balance of software programming will be performed as needed for full integration. A full system schematic is shown in Figure 10.

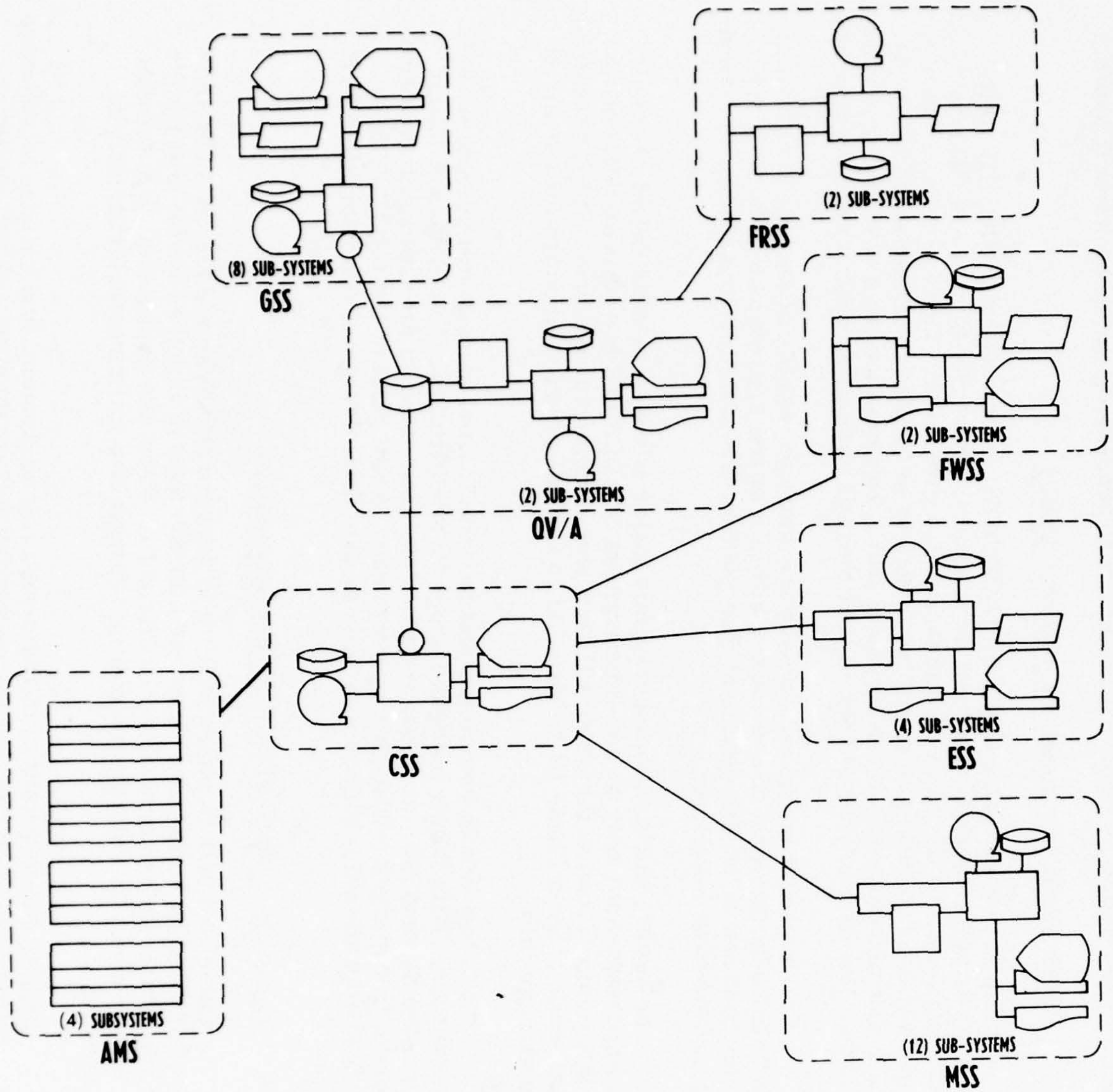


FIGURE 10

FULL SYSTEM SCHEMATIC

SECTION 6

IMPLEMENTATION PROPOSAL AND BUDGETARY COST

6.1 CONTINUING EFFORT

The magnitude of the ADDSRTS program is such that many approaches to implementation can be taken. For simplicity only, one approach is suggested together with a Mileston & Program Plan, as depicted in Figure 11. The monetary figures shown are budgetary estimates to be used only as a guide as to the magnitude of costs.

6.1.1 FY 76 Effort

It is expected that during FY 76, three portions of ADDSRTS will be funded. One will be to conduct the compaction study to establish a license free program suitable for use in the system. Another will be the design, build and test of solid state units for compaction and decompaction based upon the study. The third project will be the design, build and test of the laser film reader unit.

6.1.2 FY 77 Effort

During the balance of FY 76, vigorous effort should be expended to obtain full support for the establishment of a pilot system and the total system implementation, and to provide financial backing for the development of the Advanced Mass Store to commence in FY 77.

There should be continuation of work to design and build the controller and software programming for the laser scanner to complete the Film Reader Sub-System.

A complete System 190 (the interim Mass Storage Sub-System) and a complete Graphics Sub-System should be procured. The main controller and a portion of the software programming should also be procured. The software will be a continuing and long term effort expected to last throughout the implementation of the total system.

6.1.3 FY 78 Effort

Evaluation of the Graphics Sub-System will enable definition and procurement to be initiated for the Quality Verification and Authorization, Engineering and Manufacturing Sub-Systems.

Testing and evaluation of the Film Reader Sub-System should permit procurement of a second unit and should enable the design and building of the Film Write Sub-System to be initiated.

6.1.4 FY 79 Effort

The effort will be to interconnect the sub-systems as shown in Figure 9 and to perform analysis and evaluation of the pilot system. From this data, definition of the final configuration can be made and additional sub-systems procured.

ITEM		FY 76	FY 77	FY 78	FY 79	FY 80	FY81
PILOT SYSTEM IMPLEMENTATION							
PHASE 2	FILM READER SUB-SYSTEM						
	COMPACTION STUDY	30K					
	COMPACTOR/DECOMPACTOR	55K					
	LASER FILM READER UNIT						
	READER	165K					
	CONTROLLER		50K				
	SOFTWARE		50K				
PHASE 3	ADVANCED MASS STORE (R & D)	3,500K					
PHASE 1	MASS STORAGE SUB-SYSTEM		560K				
	CONTROL SUB-SYSTEM		250K				
	GRAPHICS SUB-SYSTEM						
	HARDWARE		150K				
	SOFTWARE		100K	100K	100K	50K	
PHASE 2	FILM WRITER SUB-SYSTEM			475K			
PHASE 1	QUALITY VERIFICATION SUB-SYSTEM			200K			
	ENGINEERING SUB-SYSTEM			150K			
	MASS STORAGE SUB-SYSTEM			150K			
FULL SYSTEM IMPLEMENTATION							
PHASE 4	ADDITIONAL SUB-SYSTEMS						
	FILM WRITER SUB-SYSTEM			330K			
	FILM READER SUB-SYSTEM				450K		
	GRAPHICS SUB-SYSTEM				1,050K		
	QUALITY VERIFICATION SUB-SYSTEM				175K		
	ADVANCED MASS STORE				1,250K	2,500K	
	ENGINEERING SUB-SYSTEM					1,650K	
	MANUFACTURING SUB-SYSTEM					450K	
FUNDING	M T	250K	1,160K	1,405K	3,025K	4,650K	
	R & D	3,500K					

FIGURE 11

MILESTONE & PROGRAM PLAN

6.1.5 FY 80 Effort

This effort will be procurement of the final sub-systems, completion of work on software programming, and final assembly of the total system. Data of operational performance will be gathered and evaluated and assembled in a final report.

An audio-visual presentation of the system will also be prepared.

SECTION 7

ECONOMIC ANALYSIS

7.1 PRESENT OPERATION

The operation of the Technical Documents Department (TDD) at NOSL was the subject of an in-depth examination in late 1974. The full details are not considered relevant to this study and are not included in this report. An abstract of the more important features as they would relate to revision of the operation are noted and reviewed below.

7.1.1 Documents Stored

A breakdown of the type, size and quantity of documents stored is listed in Table 3. From this, it is readily seen that the number of aperture cards is not directly compatible with the number of documents. This is because, in various instances, old documents could not provide sufficient quality to obtain the desired level of resolution on microfilm or are multiple sheet drawings. It is necessary in these instances to decrease the level of document reduction so that more than one aperture is required.

Item 11 (Obsolete Documents) in Table 3 refers to drawings and other related documents and describes equipment that may still be in service, even though the equipment may have been the subject of updating through ORDALTS (Ordnance Alterations). Approval for destruction or removal of these types of documents from the repository has not been granted. Ready access to such information is considered cost effective in relation to storage costs. Item 14 in Table 3 (Publications) is a broad term used to describe documents which constitute a fundamental part of drawing description and whose absence would render a drawing incomplete.

7.1.2 Activity Data

Aperture Card Activity Data - Historical (1 year - Aug 71 to Aug 72) is shown in Table 4.

This table illustrates the quantities of the various documents and their sizes. The difference between number of documents and number of aperture cards is that some documents have supplemental sheets, or are comprised of two drawing sheets.

7.1.3 Typical Process Time and Costs

Typical single document request intra-plant can be broken down as shown in Table 5.

It can be seen that the major expenses are those of writing the order, delivery of the order, logging-in for data processing, and pick-up of the reproduced copy.

Intermediate expenses are those of card withdrawal and return to the files.

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Item	Document Type	Size	Number of Documents	Number of Aperture Cards
1	Drawings	A	228,950	343,423
2	Drawings	B	242,416	363,625
3	Drawings	C	121,208	181,812
4	Drawings	D	673,380	1,010,070
5	Drawings	E	67,338	101,007
6	Drawings	Rolls	13,468	20,201
7	"L" & "SK" Dwgs	Various	1,500	2,250
8	LD's	B	112,155	672,930
9	FBM LD's	B	4,573	27,438
10	FBM Dwgs	Various	238,920	358,381
11	Obsolete Documents	Various	872,236**	1,308,355
12	NOR's & RD's	A	104,480**	130,605
13	Other Documents	Various	94,740	281,500
14	Publications	A	109,100	540,000*
		TOTALS	2,884,464	5,341,597

* Number of Sheets (Masters and Reproducibles)
** Estimated

TABLE 3 DRAWINGS AND DOCUMENTS STORED IN TDD

Number of Times Card Retrieved	Number Of Cards Retrieved	Total Card Retrievals
1	637,005	637,005
2	158,727	317,454
3	66,898	200,694
4	32,343	129,372
5	16,386	81,930
6 - 10	27,984	203,578
11 - 15	6,359	78,106
16 - 20	1,774	31,365
21 - 40	1,428	38,590
Over 40	703	74,469
TOTALS	949,607	1,792,563

1 August 1971 through 31 August 1972
(12 months - February 1972 is not included)

TABLE 4 APERTURE CARD ACTIVITY

Item	Time	Cost $
Write Reproduction Order	2 mins	.60
Deliver Order	15 mins	3.00
Log in (Clerk + Data Process)	8 mins	1.17 + .05
Card Withdrawal	1 min	.30
Reproduction	-	.07/.17
Card Return	1 min	.30
Log Out	-	.08
Pick Up	15 mins	3.00
		$8.57

TABLE 5 PROCESS TIME AND COSTS

Actual reproduction costs of 7 cents for aperture card (duplicard), and 17 cents for hard copy (paper) are considered to be competitive.

7.1.4 Breakdown of Direct Costs

The Industrial Department maintains a partial aperture card store of drawings (DDU) for work in the preparation of quotations and also in the support of current production. In breaking down the direct costs it was found that the actual costs in 1973 were as follows:

Actual Costs For 1973 (Station Related)

Station expenses (direct and indirect)

(Obtaining Documents from DDU)		
Trips to DDU	24,305	
Time Expended	4,229 x 14 hrs	= .174 hrs/trip
Cost	$54,614.29	= $12.91 hr
		or $ 2.24/trip
(For Viewing Documents at TDD)		
Trips to TDD	2,276	
Time Expended	995.8 hrs	= .478 hrs/trip
Cost	$14,491.75	= $14.55 hr
		or $ 6.37/trip
(Obtaining Document from TDD)		
Trips to TDD	4,618	
Time Expended	1,702.3 hrs	= .368 hrs/trip
Cost	$26,437.01	= $15.53/hr
		or $ 5.72/trip
Total cost of time expended		$95,543.05

Writing Reproduction Order 31,199 requests x 2 mins x $15 hr (average)	= $15,600
Two employees in DDU @ $9.35/hr (average)	= $39,000.
	$150,143

TDD expenses

Log-in Request and Process Two employees $9.35 hr (average)	= $39,000
Storing and Retrieving Cards Eight employees $9.35 hr (average)	=$156,000
	$195,000

Additional costs are incurred when a card is not available in the correct storage location. The breakdown that follows is intended as a guide rather than one based on specific details.

An average of 10 cards per week requires location research when not readily available and when no information is in the drawer indicating their whereabouts. Of the 520 cards per year, about 472 are usually easily located in drafting, duplicating, etc., and require about 8 hours per week of search time.

10 cards per week requiring location search
8 hrs/week @ $9.35/hr = $ 3,890

Of the 48 cards not located within the 8 hours per week, additional effort is expended to locate duplicards within the Engineering and Industrial Departments, or other activities and contractors who have received copies within the past year. This usually occupies one person full time at one card per week.

48 cards misplaced - 40 hrs x $12.00/hr x 48 weeks = $23,040

Of the 48 cards, 43 duplicards or replacements are recovered for re-establishment of the file. The remaining 5 cards require reconstruction of a master drawing due to the inability to obtain an up-to-date revision.

5 cards reconstructed - 40 hrs/each @ $12.00/hr = $ 2,400

These search and reconstruction costs are estimated at $29,330.

Total Direct Expense = $374,673

The Station and TDD expenses totalling $345,000 noted above can be entirely eliminated, together with approximately $30,000 indicated for search and replacement, by the implementation of ADDSRTS.

7.1.5 Intangible Costs

The intangible costs are primarily incurred as a result of: (a) poor resolution and (b) incompleteness and poor quality of contract data packages.

a. Poor Resolution can occur in three areas. Master microfilm generated in-house is individually inspected for resolution and quality. When necessary, the master document is improved and refilmed to obtain minimum standards. However, occasionally a card will be on file with a dimension line or dimension which is not clear. Film received from outside sources, whether contractor or other Navy activity, was a problem in terms of not being first generation film and therefore sub-standard on resolution requirements of MIL-D-9868. Tightening of incoming inspection and insistence on adherence to requirements have almost eliminated this as a problem; however, occasionally a card will be on file which is not perfectly legible. Thirdly, it is not practicable to examine individually each copy, whether it be duplicard or hardcopy. Consequently, poor resolution is the greatest source for illegible copy and misinterpretation of data.

b. Contract Data Packages can be either hardcopy for small contracts necessitating only a few documents or duplicards for major procurements which can entail as many as 35,000 aperture cards in one bid package to a prospective bidder. The quality and completeness of these packages are paramount since the successful bidder usually undertakes his contractual obligation from the data

in the bid package. The four major problem areas are:

Human errors in compilation
Non-current revisions
Missing data
Poor resolution.

Defective data packages are usually made known after the contract is signed; and, depending upon the size and magnitude of the defects, can result in:

Contract re-negotiation
Extended time for completion
Delayed delivery schedules
Contract price increases
Defective parts
Litigation.

The latent effect is:

Defective parts entering service
Investigation of problems and breakdowns
Ordnance Alteration (ORDALTS)
Cost claims.

It is difficult to obtain data of specific examples to relate these to defects in the bid package, and to have authoritative affirmation that they constitute a cost burden. However, two cases in which the author was a participant provide evidence that an estimated figure for intangible costs resulting from defective contract data is in excess of $2 million per year.

7.2 Cost Analysis

From the budgetary estimates presented in the Milestone and Program Plan illustrated in Figure 11, the following analysis is presented:

MT effort as proposed		$10.43 M
R&D effort for an Advanced Mass Store		$ 3.50 M
Total		$13.93 M
Completion of Document Loading		$ .160 M
Proposed cost elimination		
-- Tangible (Direct & Indirect)		$ .38 M
-- Intangible		$ 2.00 M
		$ 2.38 M/year
Estimating Annual Operating Service and Maintenance		$ .160 M
Amortization	$\frac{10.43 + .16}{2.38 - .16}$	= 4.77 years
or	$\frac{13.93 + .16}{2.38 - .16}$	= 6.35 years with R&D costs

Cost Savings Potential
(Based on Annual Operational Costs Only)

Present Cost	$\frac{\$380K}{5,341,597}$	= 7.11 cents/card
ADDSRTS Cost	$\frac{\$160K}{5,341,597}$	= 2.99 cents/card
SAVINGS	$220,000/year or	4.12 cents/card
		or 58% cost reduction

7.3 RELATED BENEFITS

The establishment of an ADDSRTS system will provide the elimination of the aforementioned tangible and intangible costs and serve as a birthplace and working demonstration of this advanced technology.

7.3.1 Additional Benefits

In addition to the cost savings the ADDSRTS system would:

a. Ensure the latest revision.

b. Ensure sound legible output.

c. Minimize duplication (majority of requests could be satisfied with short-term visual display).

d. Provide virtually instantaneous response (less than 20 seconds).

e. Enable the major portion of the 8200 man-hours currently used in obtaining documents to be better utilized.

f. Eliminate loss of misfiled documents.

g. Provide file security.

h. Permit controlled access.

7.3.2 Potential Users

The large aperture card and engineering drawing repository is not unique to NOSL. Other known large repositories within the Navy and the Army which are considered potential users of the ADDSRTS system are:

Navy	Army
NSWSES	TACOM
NUSC	AVSCOM
NAVTORPSTA	ECOM
NAFI	MICOM
NAVELEX	ARMCOM
	TROSCOM

SECTION 8

CONCLUSIONS

This study covers the high cost, manpower and volume necessary to operate a large engineering drawing and related document repository. It also stresses the need for a major breakthrough in document storage. This is not to be construed as derogatory of microfilm or microfiche, which will continue to provide a much needed service.

Examination of past technologies and curren available equipment reveals the major impediment to further advances, especially for large repositories such as NOSL. However, the fact that the Army at TACOM has installed a main system which can provide many of, but not all, the advantages of ADDSRTS serves to illustrate both the urgent need and the fact that such large systems can be cost effective.

The investigation of current and future technologies reveals that computer emerging control and data processing equipment is going to play an ever increasing role both in our everyday lives and in the business and industrial worlds. It was this strong technology thrust that has emphasized the examination of document storage in data stream form. Both technology and equipment are readily available for the transfer of data over long distances; therefore, major emphasis was directed in this study to the conversion of documents (engineering drawings - E Size) into data stream form, the volume of data, and the maintenance of resolution vital to the legibility of documents for contractual purposes.

Exhaustive search has revealed that a few companies and the Army have made studies in image conversion to data stream and resolution relationships, with the most significant work discovered that of Singer Simulation Products. It is considered that their work has established and factually proven that 35mm microfilm of E-Size engineering drawings can be scanned (by laser modulated light beam) to provide a data stream in raster scan form. This data stream can be compacted through algorithms an average of 40 to 1 to reduce the scanned data of approximately 80×10^6 pixels to approximately 2×10^6 data bits. Continuing work by that company has made possible the reduction of bits to approximately 1.5×10^6 bits by concentrating solely on the document within drawing border as against the microfilm aperture card window. At the writing of this report, it is further understood that the raster scan data has been converted by suitable software programs to vectorized formating, thus enabling the document image to be displayed on a display terminal and become capable of electronic modification.

This work establishes that the ADDSRTS concept is capable of being constructed with present technologies. It shows also that the construction could easily satisfy basic requirements. It is apparent that no company is marketing or has immediate plans to market an advanced system such as ADDSRTS.

The other major revelation of the study is that predictions for mass storage show a critical need for a breakthrough to meet future demands. It is apparent that none of the media had or was expected in the near future to provide on-line

storage for 10^{12} bits at reasonable cost. The requirement that the medium be archival narrowed the prospective supplier to one source. Examination of this product and equipment showed that on-line data bank could be readily assembled from standard units to provide the full capacity required and that costs are competitive. It was not until detailed analysis of power requirements and projected maintenance costs are evaluated that concern was expressed. The electrical power requirements to supply some 48 laser reader units was considered, together with laser life, replacement, and maintenance costs to be very high, but still justifiable with sufficient need.

A result of this study has demonstrated to one company that a major breakthrough is not only needed now in mass data storage but that there is sufficient market for the equipment. Private industry is, however, reluctant to provide major capital investment because of the present market environment. Nevertheless, stimulation by DOD through the Navy in the form of R&D effort can provide a much needed item of equipment and provide ADDSRTS systems with major cost reduction and space saving.

It is concluded that the plan and program set forth in Section 6 presents a sound, economically justifiable proposal to implement an ADDSRTS system at NOSL. The inclusion of this R&D effort will enhance not only this and similar systems but will provide a major breakthrough in mass storage that will be capable of providing massive on-line information for the next generation of equipment and systems.

SECTION 9

RECOMMENDATIONS

It is recommended that support and funding for the R&D effort in Advanced Mass Storage be vigorously pursued in the best interests of not only DOD but industry as a whole.

The implementation of an ADDSRTS system offers a major improvement in the concept of maintaining large document repositories, not only for engineering drawings and related documents, but for large document storage and retrieval systems where virtually instantaneous recall is a very important factor. The study shows that the various technologies are known but not commercially available.

The complex sub-systems and programming to provide a full system need to be designed, developed, and made operational. It is, therefore, considered that support for the ADDSRTS system falls within the scope of the Manufacturing Technology (MT) Program and that its inclusion would enhance the program and provide further demonstration of the program's service to the nation.

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This study assesses the technology and availability of equipment for providing an automated storage, retrieval and transmission system for engineering drawings by converting them into a digitized data stream. Examination of current technology and available equipment revealed that little progress has been made in the mass storage of data. Only a few companies and the Department of the Army have made studies in image conversion to data stream and resolution relationships. One company has done extensive research in the use of laser
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20. ABSTRACT (Cont'd)

scanning in the conversion to data stream of microfilm images of engineering drawings. This data stream requires approximately 80 x 10^6 bits to describe adequately an E size drawing at a suitable level of resolution. Because of the large amount of data involved, the company also examined data compaction and compression techniques for this data stream. They found that an average of 40:1 reduction was realistic, thus reducing the data per image to 2 x 10^6 bits. A mass storage concept was then formulated that is based on an analysis of this information plus a consideration of the make-up and activity at the Naval Ordnance Station, Louisville (NOSL). Review of the present and newly emerging data stream storage media indicated that no substantial breakthrough could be anticipated, especially with regard to cost per bit or the overall on-line capacity. Because the storage information must be archival, only one system was found to offer suitable storage media. Its cost per bit is competitive, and it can provide through modular units an on-line storage for 10 x 10^{12} bits or enough capacity for 5-million engineering drawings. Additional investigation has revealed that the bits per image can be further reduced to 1.5 x 10^6 and that the technology is available to provide a mass store with access of two megabits a second and a capacity of 2 x 10^{12} bits within a 2 1/2 foot cube. This study, therefore, concludes:

1. An Advanced Mass Store is important to the entire electronic data store industry and should be strongly supported.

2. An automated storage, retrieval and transmission system is practicable.

3. The technology is available for such a system.

4. Two major items of equipment, however, are not commercially available at this time:

   a. An inputting device to read engineering drawings or microfilm of engineering drawings and

   b. An outputting device to reconstruct the image on film for contract data packages.

The study which follows reviews technologies, equipment, requirements for implementation, and an economic analysis of a system for NOSL.